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BIM Applications in Conceptual Design Phase: Exploring the Abilities and Limitations of Autodesk Revit Architecture through the Generative Geometric Design Approach

Sara Ben Lashihar
University of Nebraska-Lincoln, s.benlashihar@huskers.unl.edu

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by

Sara A. Ben Lashihar

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Sara A. Ben Lashihar, MS

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Advisors: Timothy Hemsath, Steven Hardy

Autodesk Revit Architecture as one of BIM applications has shown recent improvements in creating complex forms in conceptual design phase. These improvements have been published lately in reports (Autodesk 2010; Autodesk 2009) and books (Krygiel et al. 2010). The presented abilities were introduced within a general scope, and they were not examined in detail with various generative design approaches. The generalization and the ambiguity of these publications lead designers to avoid using Revit in conceptual design phase, and use other 3D modeling softwares that are more compatible with their way of thinking. This thesis examines the abilities and limitations of this application in a particular design approach called Generative Geometric Design Approach (GGDA). This approach depends on the creation of geometric shapes as a generator in the conceptual design phase.

The awareness of these abilities and limitations in achieving GGDA renders the reliability of Revit for designers who use that approach, and provides the architectural educational systems

with an overview about the software. Additionally, the knowledge of Revit's limitations will contribute to the development of the software in future versions (Odeh and Adwan 2009, 1067; Fadezean 1999, 503).

The appropriate methodology for this examination is dependent on a multi-method tactic. The multi-method tactic is divided to: main method and confirmation method. They depend on a series of experiments that are conducted by the author in the main method, and by a number of students in the confirmation method.

Conclusively, the examination has shown that Revit Architecture has abilities and limitations in working on the first stage of GGDA, which makes it premature to depend on it entirely. Otherwise, it is recommended for the future studies about the compability of BIM applications with generative design approaches to avoid the limitations of this research and the experiments, and evaluate Revit Architecture in creating more complex geometries.

Dedication

I dedicate my thesis to my father's soul Prof. Ali Ben Lashihar (Might Allah blesses his soul with mercy) who taught me the love of knowledge and learning, to my mother Salma who supported me, to my fiancé Abd Al-Aziz who gave me new hope in life, to my sisters: Samia, Hanan, and Fatma, and last but not least to my great brave country Libya with my prays for freedom soon.

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Chapter 1. Introduction

Autodesk Revit Architecture is one of a range of BIM applications available today. It is considered the most used and popular BIM tool in the Architecture, Engineering and Construction (AEC) industry in the U.S (Eastman et al. 2008, 57). It has been used widely since its appearance in 2002 by Autodesk Company (Eastman et al. 2008, 57). In its latest versions, Revit shows improvements (Autodesk 2010; Autodesk 2009) in design thinking at the conceptual design phase. These improvements are demonstrated through Autodesk reports (Autodesk 2007), training books (Krygiel et al. 2010), and YouTube videos[1]. These publications and materials present new abilities of Revit, and focus on creating more complex forms that were difficult and even impossible in previous versions.

However, Revit's interface and modeler are still ambiguous and unclear, because the new modeling abilities are usually presented in a general way that studies them slightly in terms of their compability with different ways of thinking of the designers and their generative design approaches. The fact that the generative design process is a "subjective" process (Groat and Wang 2002, 104) and has no defined rules or boundaries; leads each designer to follow his/her own approach (Abdelhameed 2004, 91). Designers usually choose approaches that suit their architectural background, design program, and personal knowledge (Abdelhameed 2004, 92). Thus, designers tend to use softwares that suit their generative design approaches. This thesis explores and evaluates more about the

[1] YouTube. http://www.youtube.com/

abilities and limitations of Revit in the conceptual design phase specifically within in an approach called Generative Geometric Design Approach (GGDA). This examination attempts to clarify part of the ambiguity about Revit by presenting its suitability with this approach, and investigates its reliability.

The understanding of the abilities and limitations of Revit Architecture by designers who use GGDA provides them with the fact about the compability of the software with their approach in conceptualizing their geometric design ideas. This fact helps them to decide their use of Revit in the conceptual design phase. The use of Revit in the conceptual design phase has a significant impact on the work flow of the design process. The workflow will be accelerated and be more efficient, if these designers use Revit in all design phases without interruption. In this case, they will avoid the process of importing and exporting files and models from other 3D modeling softwares. The process of importing and exporting files may cause technical difficulties and impair developments, if designers decided to make modifications in the design concept at advanced stages of the design process. As a result, the workflow will be interrupted, which could negatively affect the timetable of the project (Autodesk 2007, 1).

In addition, this study is considered to be an extension of previous academic studies about BIM. There are few academic studies have addressed the feasibility of BIM applications in the conceptual design phase, and most of recent studies have evaluated BIM applications in certain design phases including: information gathering, preparation of documents and schedules, collaboration, budget (Avila 2009), and structural

integration (Meadati 2007). For instance, a Master student in California Polytechnic State University (Avila 2009) studied the benefits of BIM in the programming and in the conceptual design phase. The study focused on specific stages in the design process; gathering information, preparing design program, timetable, and detailed drawings, whereas it disregarded the stage of conceiving the design concept. This research concentrates on the conceptual design phase by studying the compatibility of Revit with the generative design approach GGDA.

1.1. Generative Geometric Design Approach (GGDA)

GGDA is a design method in the conceptual design phase. It is adopted by some designers and architects to generate the design concept. Generative design approaches in the conceptual design phase are subjective and intuitive processes: they have no rules or boundaries to define them accurately. GGDA is a technique with the same merit. Therefore, this technique has to be defined precisely to proceed with propositional components of Research Activity (Groat and Wang 2002, 105). As a result, GGDA is classified with three main stages (Mallasi 2007, 708-710): that rely mainly on the initial shapes and geometries, to conceive the design concept. The following few points discuss the three key stages of this approach:

1. ***Initial Geometry Preparation (IGP)* stage*:*** (Mallasi 2007, 708) As a start point of GGDA, the designer in this stage converts his/her idea or sketch to basic or complicated geometry. He/she begins the configuration of the design concept with 2D shape or 3D

geometry, whether it was sketched previously or not yet conceived. Figure 1 shows the creation process of tetrahedron geometry in Revit Architecture by the author. To create tetrahedron in Revit, the geometry was abstracted to three prism geometries.

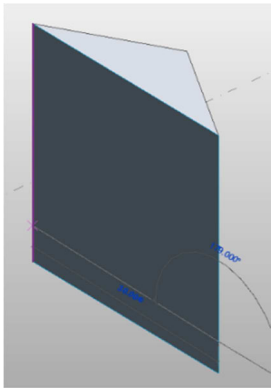


Figure 1: Starting with prism geometry as a step in creating tetrahedron geometry.

2. ***Geometry Configuration and Transformation (GCT) stage:*** (Mallasi 2007, 709-710) The primary form is developed in that stage. This development process varies upon the goal of the designer. In that development process, a number of CAD operations could be applied on the basic form to develop it. These operations include; Boolean operations (union, subtraction...), Editing operations (cloning, rotation...), NURBS operations (editing control points), and different other operations: they are provided in the design software. At the end of this stage, a clear and interpreted form of the concept is obtained. Figure 2 illustrates the experiment of creating tetrahedron geometry in the second stage of GGDA. Three identical prisms were developed to three pyramids in the first stage. At last, these three pyramids were joined to create the tetrahedron.

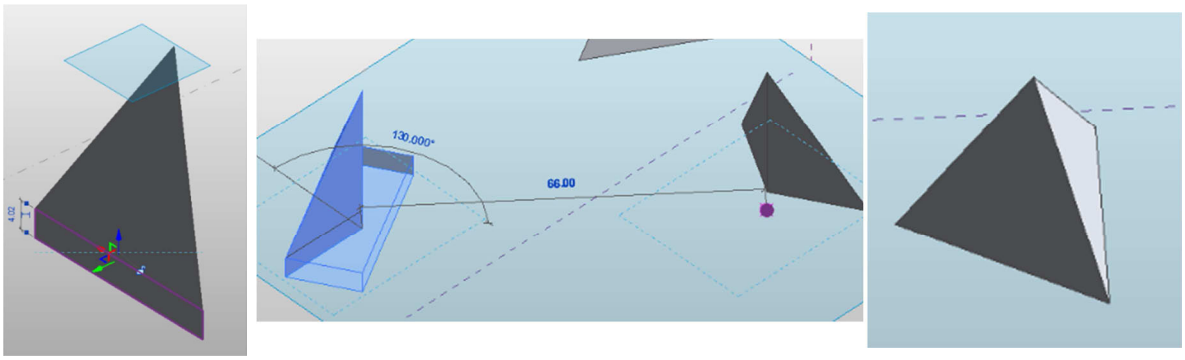


Figure 2: Developing the prism geometry to a quarter of tetrahedron.

3. ***Final Form Recognizability (FFR) stage*:** (Mallasi 2007, 710) In this stage, designers transform the design form to a real building. In this transformation, designers add different components in BIM application to the forms. These components include walls, windows, curtain walls, floors, ceiling, and so on. The components differ upon the used BIM application. Figure 3 presents the result of the transformation process of tetrahedron geometry to a real building in Revit Architecture.

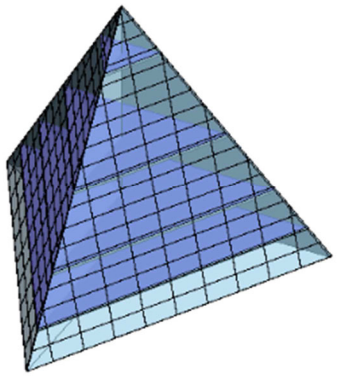


Figure 3: Applying Revit's components on tetrahedron to transform it to a real building.

1.1.1. Architects used GGDA

This section introduces examples of architects who used GGDA in some of their design projects. These architects include Peter Eisenman and Bruce Goff.

1.1.1.1. Peter Eisenman

This approach has been used by well-known architects in creating the design concepts of some of their buildings. Peter Eisenman followed that approach in designing Aronoff Center of Design and Arts in University of Cincinnati in 1989. He used two shapes to configure the mass of that building; a segmented rectangular and a zigzag as shown in Figure 4. The last shape was derived from the pre -existing building. He applied several editing operations on these two geometries, such as; torquing, overlapping and oscillating operation (Jencks 1997, 172). This process helped the designer to achieve a remarkable form.

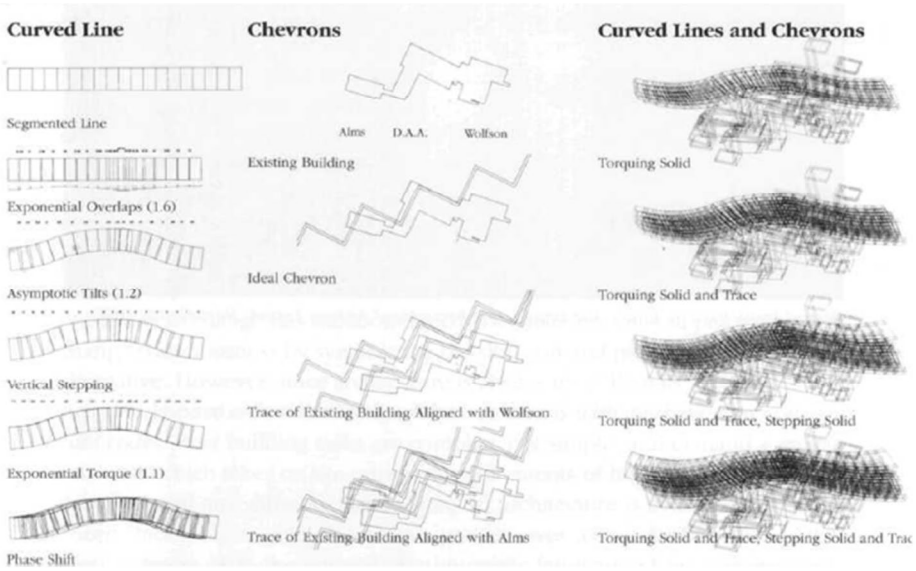


Figure 4: Eisenman used initial shapes in conceiving the design concept form (Jencks 1997, 170).

1.1.1.2. Bruce Goff

Self-similarity concept in mathematics depends on fractals as its generative basic principle. Fractals originate from nature (Jencks 1997, 43). The essential units of their compositions are initial 2D shapes. Bruce Goff achieved the self-similarity in his projects before the emergence of this concept. His design of Joe Price Studio in 1956 is a good example of this achievement. The design concept of Studio's building consists of various initial shapes; triangulars, hexagons, and trihexes (Jencks 1997, 42-44). They were copied and linked mathematically, which helped the architect to generate a creative and novel idea for his time as illustrated in Figure 5.

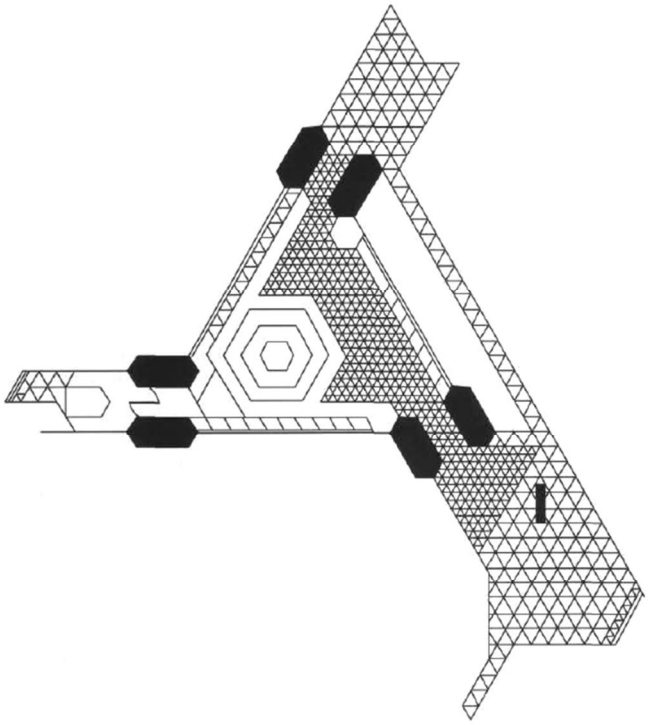


Figure 5: Joe Price Studio, Oklahoma, 1956 (Jenkes 1997, 42).

1.2. Why Revit Architecture?

Several BIM applications are available today, and they are used broadly in AEC industry. Each application has its own advantages and disadvantages. No design application is free of defects and has the full options to accomplish all the design objectives (Eastman et al. 2008, 14).

The table in Appendix A presents a comparison between most popular BIM applications at the present: Autodesk Revit, Bentely, ArchiCAD, Digital Project, AutoCAD, AllPlan, and DProfiler. This comparison reviews the fundamental properties and features for each application (Devon et al.2007, 229). It also presents the main advantages and disadvantages of each software. The goal of this comparison is to clarify the reasons of choosing Revit Architecture among these BIM applications to be studied in that thesis.

It is noted that each of the comparative application has its advantages and disadvantages. However, conceptual massing abilities are the notable features in this table because these abilities apply most directly to GGDA. According to the comparison, Bentley and Digital Project applications have powerful abilities in creating complex forms and geometries. Bentley has the similar design powers of creating forms as Sketchup has (Khemlani 2009), while Digital Project is being used by Frank Gehry in creating his organic buildings (Eastman et al. 2008, 60). It is the same case with Allplan application which has a considerable capacity of creating organic shapes (Khemlani 2008) since its previous versions, whereas DProfiler has limitations in spite of its equivalent power with Sketchup

in 3D modeling method (Khemlani 2008). On another hand, Revit (Eastman et al. 2008, 58) and ArchiCAD (Khemlani 2009) have limited abilities in creating complex geometries among the other BIM applications, even though the massing tools and methods of Revit have been enhanced recently(Krygiel et al. 2010).

Although both Revit and ArchiCAD have limitations in creating complex forms, Revit Architecture was chosen as the main topic for this thesis for the following reasons:

1. According to a survey was conducted in 2010 (Ben Lashihar 2010, 4), Revit is has shown to be the most used BIM application among the students of both architecture and interior design departments in the University of Nebraska-Lincoln (UNL) as shown in Chart 1.

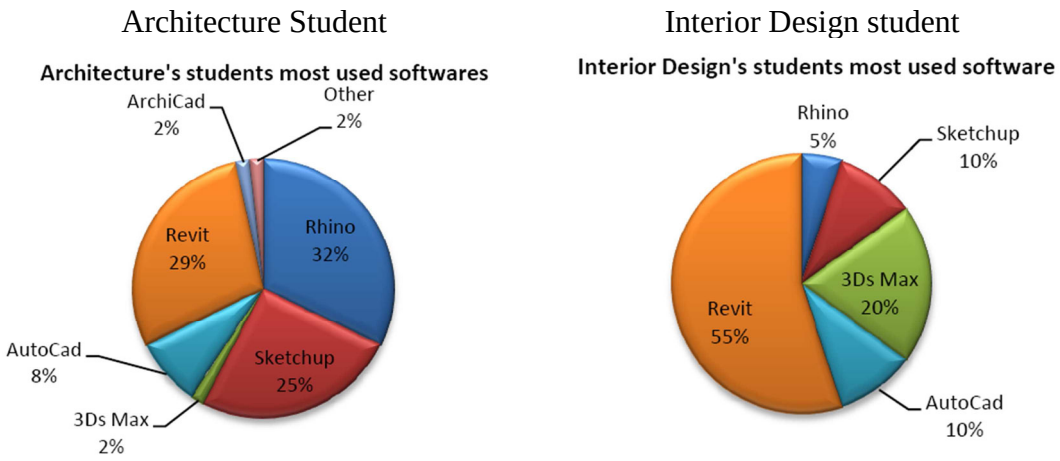


Chart 1: The results of the survey: "What is your favorite software?" for UNL's students and faculty members (Ben Lashihar 2010, 4).

2. Revit is considered the current market leader and the most used BIM application in the U.S industry (Becerik-Gerber and Rice 2010, 191). Chart 1 and Chart 2 provides the final statistics of the most used BIM application in U.S industry.

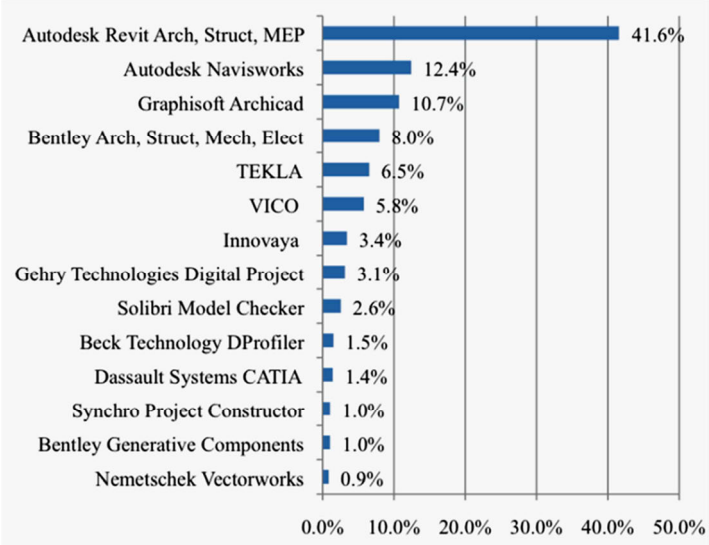


Chart 2: Shows the most used BIM applications in U.S industry in 2010 (Becerik-Gerber and Rice 2010, 191).

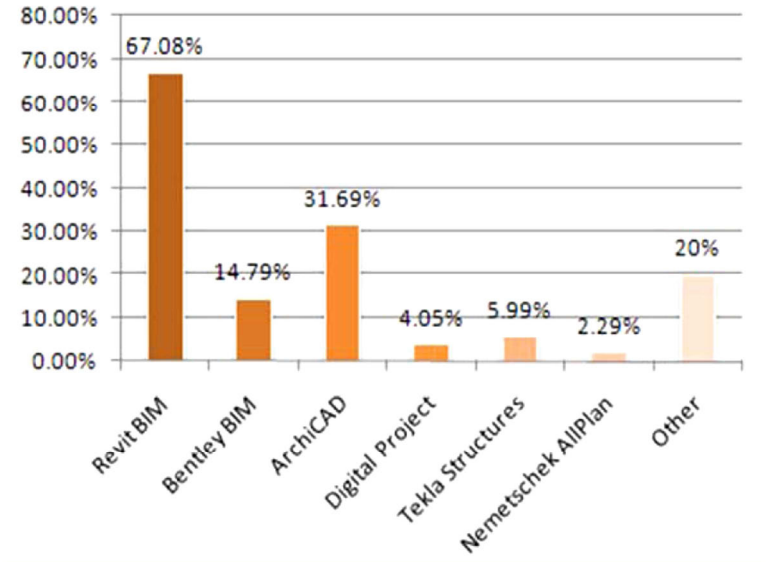


Chart 3: Shows the most used BIM applications by registered subscribers of AECbytes in 2007 (Khemlani 2007).

3. Some firms and designers, who adopted Revit in their design process, still believe that Revit Architecture has limitations in creating complex forms. Therefore, they use other 3D modeling softwares in creating the design concept.

4. Preliminary geometric forms still dominate most of the design concepts of several design projects for well-known firms that work on Autodesk Revit.

Chapter 2. Literature Review

Research papers and reports are published annually about BIM applications. They demonstrated many benefits of BIM during its use in the design process. The studies include: Autodesk reports (Autodesk 2011; Autodesk 2009; Autodesk 2007), academic studies (Avila 2009; Christenson 2006; Meadati 2007), books (Eastman et al. 2008; Krygiel et al. 2010), etc. These studies praised the valuable contribution of BIM in terms of time manner, cost reduction, and error diminishing. Conversely, comprehensive studies about the effectiveness of BIM applications in the conceptual design phase are few and rare to find.

In the case of Revit Architecture, recent publications such as the book "*Mastering Autodesk Revit Architecture 2011"* (Krygiel et al. 2010), demonstrate the ability in creating complex geometries. The evaluation in these publications shows the positive side of Revit in conceptualizing the design ideas. For instance, an Autodesk report claimed that the new enhancements in Revit support the designers' ways of thinking "Autodesk Revit Architecture 2010 software works the way architects and designers think..."(Autodesk 2009). The report has no concrete evidence or objective study to prove this fact. Therefore, the availability of academic studies that explore the compatibility of Revit as a design thinking tool, are necessary.

The main purpose of this thesis is to benefit the users of Revit. It does not aim to profit the software's makers. The thesis aims to study the feasibility of Revit Architecture by exploring its abilities and limitations in the conceptual design phase, using GGDA.

The literature review chapter presents previous studies about BIM, Revit and generative design approaches. These studies include research papers, reports, white papers, and books. The review of these studies confirms the previous discussion for the need of detailed studies about the compatibility of Revit with different ways of design thinking. As well, it illustrates the excessive focus of these studies on the benefits of BIM applications in particular design phases.

2.1. Studies about Generative Design Approaches

The definition of Generative Geometric Design Approach GGDA in this thesis was derived from a research paper presented by Zaki Mallasi "***Applying Generative Modeling Procedure to Explore Architectural Forms***" (Mallasi 2007). This paper studied a process of creating design concepts depending on primary shapes and geometries. The paper showed how primary shapes and geometries can be developed to complex masses through different editing operations, such as copying, rotating, mirroring, etc. The author derived the process from a mathematical technique that formulates Spirolateral shapes (Mallasi 2007, 700). This technique relies on developing initial 2D and 3d shapes as shown in Figure 6. In addition, the author of this paper developed a computer program

that is compatible with the process. This program is called ArchiGen, and it is embedded within ArchiCAD software.

Accordingly, the presented technique and its stages were adopted, and named with GGDA because Mallasi considered this process as a generative design language in general. The main goal of this paper also was developing a program called ArchiGen that can be compatible to this process. The development of this program was probably a result of prior belief by the author that this process cannot be applied on ArchiCAD. In contrast, the main goal of this thesis is to apply this process on one of BIM applications which is Revit Architecture to explore the compability of this software with the approach. In addition, the methodology of the paper was carried out by the author, and there were no variables that were analyzed or included to the methodology. Furthermore, the author classified the used shapes in the methodology to three different categories depending on the availability of these shapes in ArchiCAD, whereas the classification of the used geometries in my thesis was depending on the complexity standard.

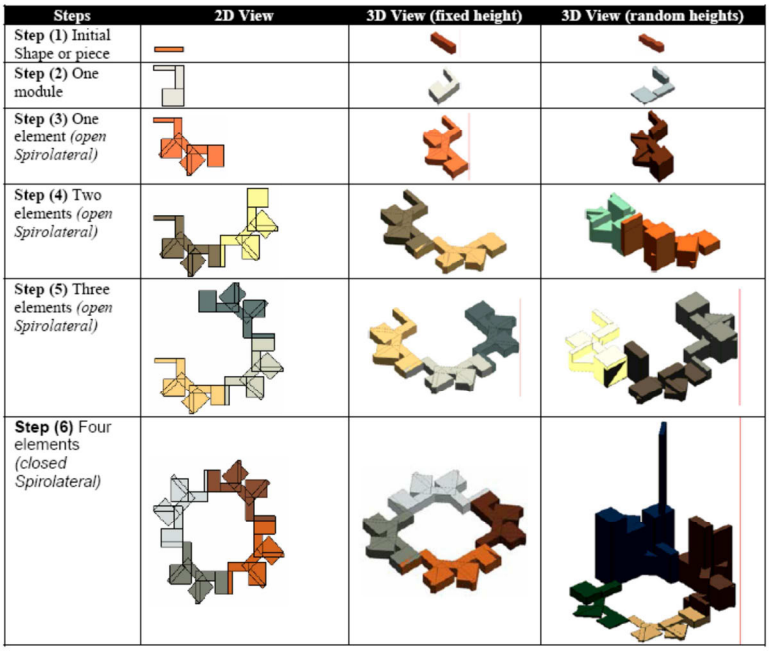


Figure 6: The main steps that were configured by Mallasi in creating Spirolateral shapes (Mallasi 2007, 702).

In 2007, Abdelhameed and Kobayashi (Abdelhameed and Kobayashi 2007) presented a design approach in conceptual design phase. The approach was called Keep It Simple and Stupid (KISS) Modeling. This approach depends on a space layout as a basic unit of its process. According to the author, that approach is simpler than other traditional design approaches. He stated that KISS Modeling approach follows a technique of one step for each time period. That technique helps designers to recognize the changes in the form during modeling. In other approaches, these changes cannot be observed until the end of the process. In KISS Modeling application, space layouts are saved as KISS files as shown in Figure 7. Then, they are imported to 3Ds Max to develop them (Abdelhameed and Kobayashi 2007, 751).

The process of KISS approach seems simple and similar to GGDA, despite the difference of using spatial units instead of basic geometries. Additionally, the researcher developed a system that is compatible with the approach "KISS modeling system" and did not apply it on existed design softwares. The further goal of introducing this paper is to emphasize on the diversity of generative design approaches, and to illustrate some examples of studies about these approaches.

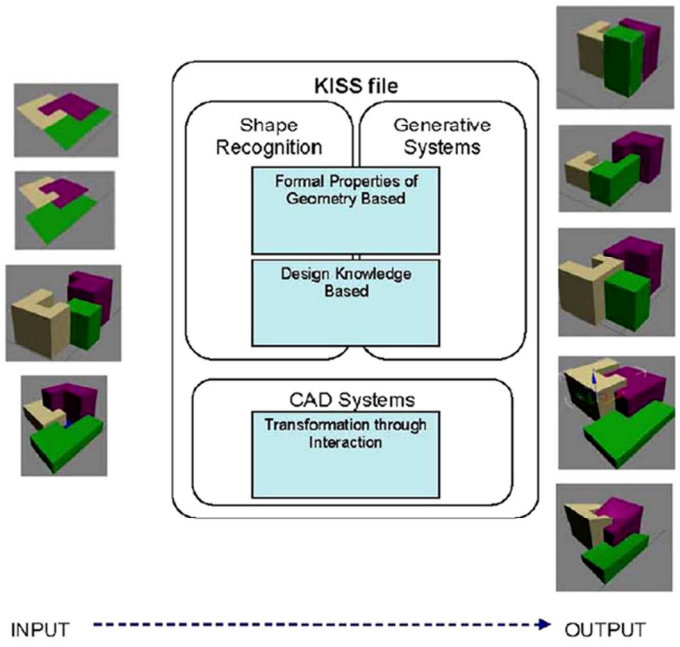


Figure 7: The methodology of KISS modeling approach (Abdelhameed and Kobayashi 2007, 750).

In another study, Boeykens and Nueckermans (2006) introduced a different design approach in "***Improving Design Workflow in Architectural Design Application***" paper. The purpose of this paper is to present an approach that achieves a flexible design process. Designers in the flexible design process have the ability to transit back and forth between the design phases easily without obstacles or technical problems.

The approach works on three main design phases; sketch design, preliminary design, and construction design phase as displayed in Figure 8. Each of these phases is divided to three Scale Levels; Masterplan, Block and Space Scale Level (Figure 9). The main function of the approach is to accomplish a flexible transition between these scales and phases. Efficient transition provides designers with the ability to make design changes, whether in the concept phase or in detailed drawing phase. The approach was evaluated on three BIM applications include: Autodesk Architecture Desktop, ArchiCAD, and Autodesk Revit. The evaluation proved that the approach cannot be applied to the three BIM applications easily. The paper concludes that these BIM applications have no flexibility to work back and forth in the design process. They are only one way design applications (Boeykens and Nueckermans 2006, 12). The users of these applications cannot make any design improvement at advanced phases in the design process.

This paper also demonstrates a new design approach that is different from GGDA with its stages. The goal of Boeykens and Nueckermans is to fund an approach that facilitates the design process and makes it more flexible. The common point of this study with that thesis is the process of applying the new design approach on three existed design softwares which are two of them are BIM applications. "Improving Design Workflow in Architectural Design Application" paper is equivalent to the thesis in the content and in the methodology. Therefore, that thesis can be considered an extension study for this paper by applying a different approach on one of the used BIM applications.

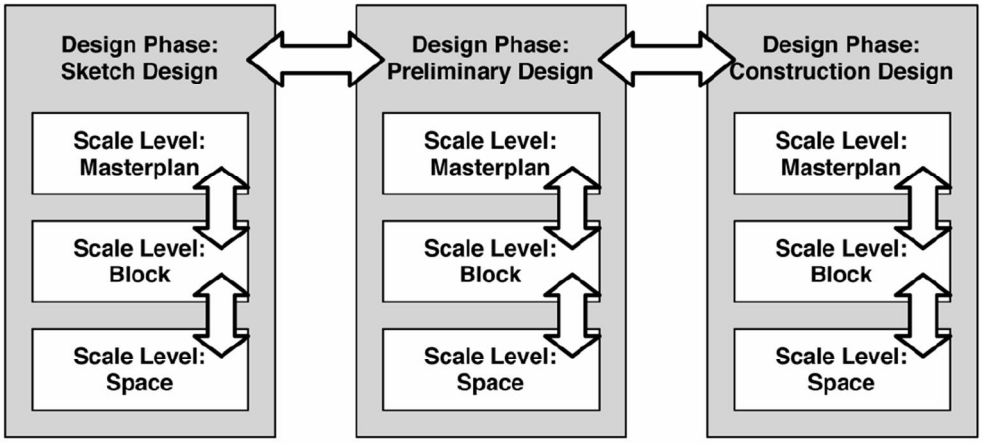


Figure 8: The possible transitions between phases and Scales (Boeykens and Nueckermans 2006, 11).

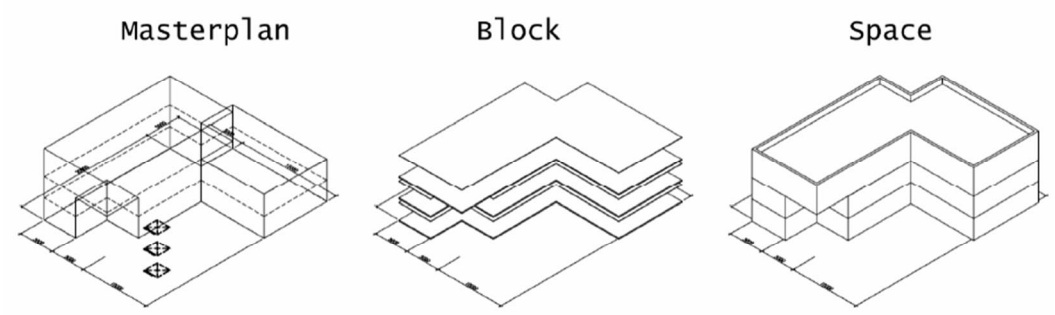


Figure 9: The three scale levels that each phase is divided to. (Boeykens and Nueckermans 2006, 11).

2.2. Studies about the benefits of BIM

As mentioned before, several studies have focused on BIM and its benefits. "***BIM Handbook: A Guide to Building Information Modeling***" Book (Eastman et al. 2008) is one of these studies. It includes precious information about BIM; current applications, benefits, problems, instructions for every disciplines, and case studies at the end of the book (Eastman et al. 2008, 57, 16, 319).

The book studied the use of BIM in all design phases, whereas it did not address completely the problems of BIM applications. Also, it presented the conceptual design phase briefly, and it does not contain examples of buildings with complicated forms that were designed by BIM. Most of the case studies in the book have very basic geometric buildings, except for Beijing National Center (Eastman et al. 2008, 375) which building was formulated by using Microstation VBA scripts, and Rhino (Eastman et al. 2008, 379). The book could be more informative and valuable if it discussed both positive and negative aspects of BIM. Concisely, the conceptual phase was not discussed widely in this book.

"***Programming and Conceptual Design using building information modeling programming***"(Avila 2009) is one of the theses that has the same topic. The main purpose of this thesis was to investigate the benefits of BIM in the programming and the conceptual design phases. The author focused considerably on the benefits of BIM in terms of efficient collaboration between the design members, the automatic preparation of documents and schedules, and the effective analysis of both project's information and the model. In the author's review of thesis, the conceptual massing phase was not examined at all. The main concentration of this thesis was just on the environmental analysis, cost, and time saving. In addition, the case studies of the thesis were building with simple forms, which can be easily modeled by BIM applications. If the author of that thesis analyzed complicated mass buildings in the conceptual design phase, the results probably will be different.

SmartMarket report (Young Jr et al. 2009) is another study about BIM. It was prepared by McGraw-Hill Construction 2009. The report addresses the benefits of BIM in terms of Return of Investment value (ROI), collaboration, and communication. Furthermore, it studies the adoption rate of BIM to date. In general the report focuses on evaluating the benefits and problems of BIM and its effects on ROI value, cost, and budget issues in order to develop and enhance the productivity in future. The authors used a survey in which covered industrial professionals and firms. In addition to the survey, they presented a series of study cases to testify the addressed benefits and problems and their effects on design members.

The report generally has focused on the certain aspects: ROI, collaboration, and communication in its study. As mentioned before, the authors concentrated their study on economic and financial effects of BIM on the projects and on the members of design. In brief, the report didn't analyze the conceptual design phase. As a consequence, this thesis will be considered as a complementary study of that report and other similar studies.

A PhD engineering student at the University of Nebraska prepared a dissertation called "***Integration of Construction Process Documents into Building Information Modeling***" (Meadati 2007). The student had raised in his research a problem of BIM that concerns the structural design phase. The problem is based on the lack integration between the structural BIM model and the structural documentations. The method that was employed in this research had achieved the integration. The author developed a 4D as-built in three BIM applications; Autodesk, Bentley, and ArchiCAD. Then, he scripted a link connects each of these models to Microsoft Access. That process helped to produce structural

reports and time schedules for the structure design phase. This dissertation has contributed effectively in providing a solution for BIM problem in the construction design phase. Such studies will certainly help to raise the productive level of BIM in the design process.

2.3. Studies about Revit

The abilities and limitations of Revit were evaluated in a paper (Christenson 2006) by a faculty member in university of Maryland. The professor employed one of his courses in the evaluation process. The evaluation focused on the phase of construction documentation. Therefore, the students of the course are demanded to prepare the construction details of a simple rectangular building by using Revit. During the preparation of details, the students are required to submit an evaluation of the observed abilities and obstacles that they noticed during their working.

In brief, the paper presented a similar topic to that thesis on a different design phase. The researcher has concluded many benefits and abilities and few limitations of using Revit in construction documentation phase. It should be noted that the simple form of the course project has a great role in the results of the evaluation. Revit has shown difficulties despite the simplicity of the building form, which arise out that question; what the results will be if the chosen project in that course have more complicated forms? The results certainly will be different. The students will face greater challenges, and they will have different their reviews.

2.4. Projects with Revit Use

2.4.1. Meraas Tower

Meraas Tower project in Dubai is one of the projects that Revit has been used in their designs. Revit in this project was used in preparing the detailed drawings, whereas Rhinoceros and Grasshopper were used in creating the conceptual mass (Peronto et al. 2009, 163-164) which has elliptic cone geometry (Figure 10). The question is; why these firms did not use Revit in creating the mass which has not a high level of complexity?

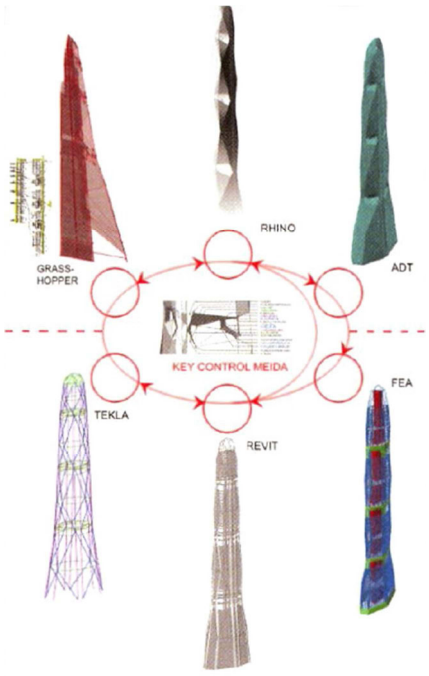


Figure 10: The workflow that was followed in designing Meraas Tower (Peronto et al. 2009, 165).

2.4.2. World Trade Center, Tower I

In 2003, SOM firm adopted Revit to use it in the design process of WTC. At first, the company decided to use Revit only in the analyzing process of the project's site. During the process of analyzing, designers found that Revit is easy to use, which encouraged them to design the entire building by Revit (Figure 12). They justified their employment of Revit in the entire design process that it helped them to design the tower in shorter time. That benefit persuaded SOM to use Revit in the design process of its future project (Architectural Transformations via BIM 2009, 52).

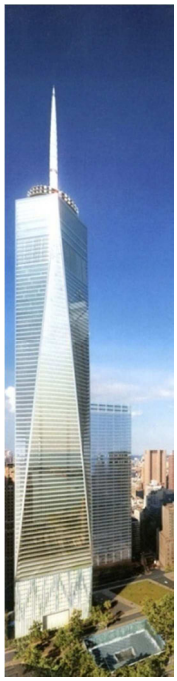


Figure 11: The new TWC by SOM firm (Architectural Transformations via BIM 2009, 45).

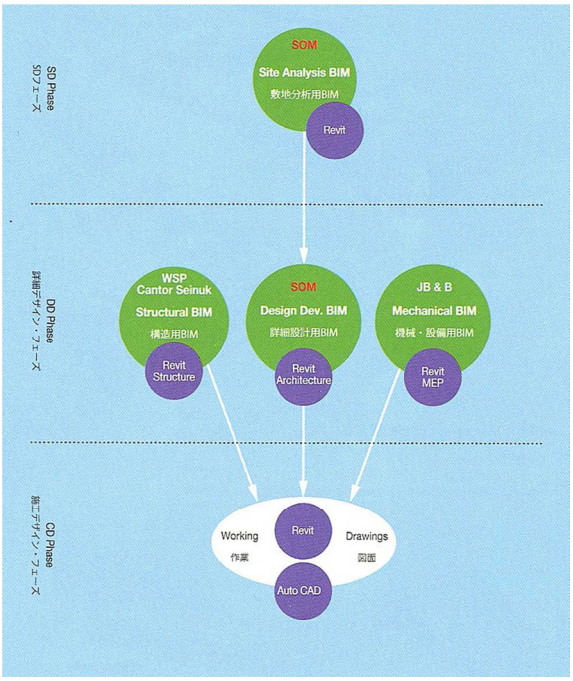


Figure 12: The diagram shows the design phases that Revit was used in (Architectural Transformations via BIM 2009, 42).

The mass of the tower is originated from prism geometry with square base as shown in Figure 11. The edges of the prism were chamfered (Architectural Transformations via

BIM 2009, 44). That process led to obtain a mass with a square plan for the first floor, a triangular plan for the roof floor, and octagonal plans in between. It can be noted, that the mass was created by using GGDA, and Revit proved its ability to create it.

2.4.3. Lotte Super Tower

Lotte Tower in Korea in Figure 13 is also designed by SOM firm. The building is expected to be the tallest tower in Asia in 2014 (Architectural Transformations via BIM 2009). In the design process of this project, different design softwares were used to create the design concept and to analyze it. These softwares include 3Ds Max, Sketchup, Ecotec, and NavisWorks (see Figure 14). Revit was only employed in the design development phase, whereas Rhinoceros helped in the transferring process of the mass.

Figure 13: Lotte Tower in Korea by SOM (Architectural Transformations via BIM 2009).

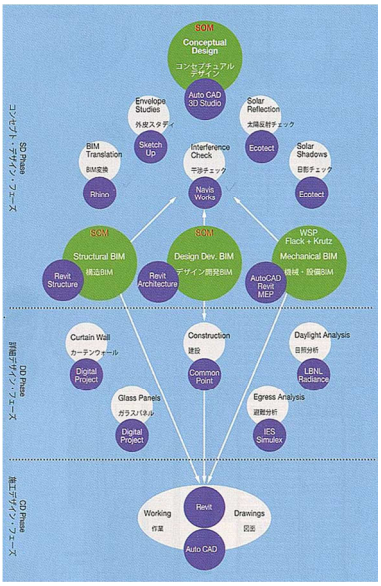


Figure 14: The diagram shows the design phases that Revit was used in (Architectural Transformations via BIM 2009).

The mass of the building can be formulated using GGDA by editing cone geometry with some Boolean operations. However, other 3D modeling softwares were used to generate the mass for non-mentioned reasons.

2.5. Autodesk Reports about Revit Architecture

In a report that was prepared by Autodesk company (Autodesk 2008), five common fallacies about BIM were addressed and reviewed. One of these fallacies that is related to the topic of this thesis was the accessibility. Accessibility is considered one of obstacles that lead design firms to not adopt BIM. The problem lies in the unfamiliarity of BIM applications by CAD users. CAD users believe that it takes long time to be familiar with BIM tools, and probably these tools are not compatible with their ways of thinking. Autodesk stated that Revit, as one of BIM applications, is easy to learn, and it suits all ways of design thinking. The report cited some case studies for design companies that found no difficulties in adopting Revit quickly. Martinez + Cutri Corporation is one of these firms. That firm trained three of its employees to use Revit for two-week session. That training enabled the company to adopt Revit quickly and work on it in a real project. The report cited that example to prove that Revit has an easy interface to deal with, which led Martinez + Curti Corporation to adopt in just two weeks. But, the question is; can that example be circulated on all other design companies? Do other design companies follow the same generative design approach that followed by that corporation?

If we analyze the mass of the building that shown in Figure 15 according to GGDA, we can notice that the mass is consisted of a set of prisms. And if we assume that the

designers of that project follow GGDA in modeling the mass, and they choose to work on tetrahedron instead of prism. Will they find Revit that easy to be adopted quickly?

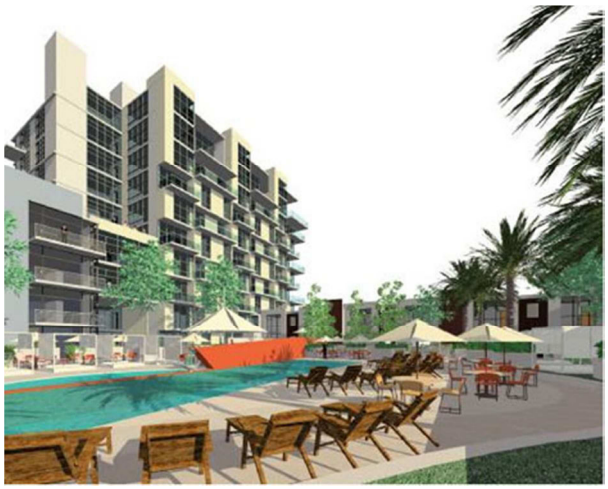


Figure 15: Martinez + Curti's project with BIM (Autodesk 2008, 4).

Another misconception about BIM concerns this research was addressed in that report. It is about the negative effects of BIM on the workflow of the design process. The report confirmed by a web survey that 82% of BIM users have no problem with the continuity of their workflow. Moreover, BIM has contributed significantly in the success of the workflow of many projects. Glotman-Simpson Company emphasized that BIM played a significant role in designing the Mixed-use Tower project in San Diego (Figure 16). In this project, BIM improved the workflow between the designers and the drafters. This improvement helped in achieving a successful design.

Figure 16: The mixed-Use Tower by Glotman-Simpson (Autodesk 2008, 5).

The mixed-Use Tower project as the Martinez + Curti project cannot be circulated on all design firms. The simple forms of these buildings could be resulted easily by using GGDA. The mass here can be generated from basic prism geometry. But in the case that the designers chose Octahedron geometry instead of Prism as the basic unit of their concept, would that affect the workflow more greatly?

In additional report "***Build Better World***" (Autodesk 2008), Autodesk presented the abilities of its BIM products by introducing some companies that have successful projects with BIM. HOK was one of these companies, which is considered one of the largest design companies in the world that adopted Revit in 2005. The report presented the history of HOK's adoption of BIM with reviewing a list of its successful projects by Revit.

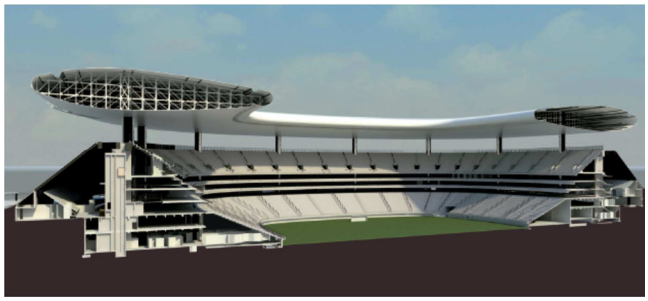


Figure 17: JVC Culture, Convention, and Business Center in Guadalajara, Mexico. Courtesy of HOK (Autodesk 2008).

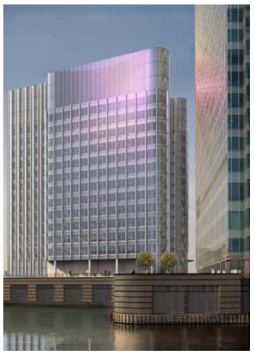


Figure 18: 5 Churchill Place project at Canary Wharf (HOK 2011).

Figure 19: Veterinary Medicine Research Facility at University of California[2]. Geometry: prism > simple.

Figure 20: Emory University Psychology Building (HOK 2011)
Geometry: prism > simple.

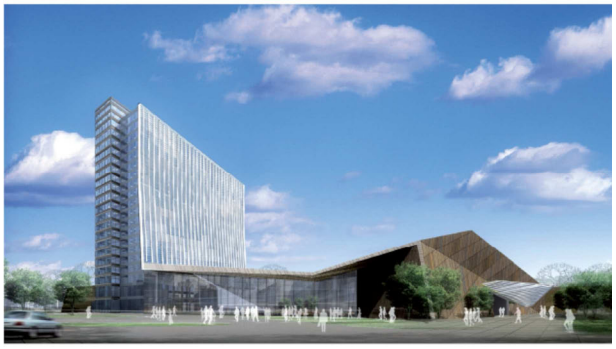


Figure 21: Sheraton Ulaanbaatar Hotel, Mongolia (Autodesk 2008) Geometry: Cuboids + Polyhedron > semi-complicated.

Figure 22: Hailey bury School, Almaty (HOK 2011) Geometry: Hyperbolic Cylinder > complicated.

[2] Flinco Constructive Solutions, "University of California Davis, Veterinary Medicine 3A Building," (2009), http://www.flintco.com/experience/education/university-of-california-davis,-veterinary-medicine-3a-building.aspx

The presented projects in that report were analyzed by the author of this thesis according to GGDA. In the previous figures, each building was analyzed to its initial origin geometry. The results show a variation in the complexity of the resulted initial geometries, but the simple geometry dominates most of these buildings. This domination explore the difficulties that HOK firm might face in creating buildings with more complicated geometries by Revit, which lead the company to prefer simple forms for its projects.

A tutorial Book about Revit Architecture 2011 (Krygiel et al. 2010) has been published by Autodesk. This book had covered all design process phases, including a special chapter (Krygiel et al. 2010, 255) for conceptual massing method. The authors introduced this chapter by creating different kinds of geometries "solids and surfaces" with various levels of complexity. This chapter was presented as a confirmation for the great abilities of Revit Architecture in creating any complicated mass that the designer wants.
The modeling and massing chapter in this book has studied some of the geometries that will be accomplished in this thesis. However, these geometers will be generated according to GGDA, as well as to other geometries that were not included to this book which all of them will be examined in depth.

2.6. Studies about Experiments and Interface Evaluation

"***Is VR an effective communication medium for buildings design?***" (Calderon et al. 2000) is one of the studies that helped the researcher of this thesis to prepare the

experiments of the thesis's methodology, and to arrange the questionnaires that were answered by the participants in the confirmation method before and after the experiments. This study included a development of an experiment were used to assess the performance of the virtual reality VR in the early stages of construction projects .The study aims to explore the promising technologies of VR in the field of visual cognition as a future alternative of the common 2D presentations. To achieve the evaluation process, ASSET application was developed to determine the abilities of VR in the briefing design phase (Calderon et al. 2000, 3). The researchers had identified the variables of the experiment and the executive parts of the evaluation process which were adopted for this thesis to evaluate Revit Architecture. The evaluation process include three main parts: the first part aims to identify the technical and human factors that might affect the experiment. The human factors were determined by using a questionnaire was answered by the participants of the experiments. This questionnaire gave a profile about each participant in terms of: psychological and health status, age, weekly hours of using computer, and previous experience. The technical specifications of the used computers in the experiments were determined to ensure the smooth performance of the experiments. In the second part of the evaluation process, the participates asked to work on a set of tasks. These tasks were explained to the participants before they start work on the tasks. Another questionnaire was also filled out by the participants in the third part of the process. This questionnaire concerned an evaluation by the participants about their tasks (Calderon et al. 2000, 5).

"***A Proposed index of Usability: a Method for Comparing the Relative Usability of Different Software Systems***" (Lin et al. 1997) is a study that presents a method of evaluating any software's interface. This method was used by the researcher in this thesis in the evaluation process of both Revit architecture and Rhinoceros interfaces. This method depends on eight human factors for the evaluation process. These factors include: *compatibility, consistency, flexibility, learnability, minimal action, minimal memory load, perceptual limitation, and user guidance* (Lin et al. 1997, 270). For each of these factors, a number of questions should be answered to obtain the level that the interface has for each factor. In Appendix D, the researcher followed that method by answering these questions about the interface of both Revit and Rhinoceros. The researcher also used another study "***Guidelines for Designing User Interface Software***" (Smith and Mosier). This study explains the questions that are included in the previous study comprehensively; the researcher used this study because of the difficulty of understanding some of computer's science terminology. Some of these questions were also used in preparing the questions of the post-questionnaire that the participates of the confirmation method were answered after the experiment to evaluate the interface of Revit Architecture.

Through this chapter, it can be noted the multiple studies about different design approaches, which illustrates the awareness of the researchers of the importance to study these approaches extensively, and affirms the diversity of the generative design approaches. One of these studies had been addressed the GGDA (Mallasi 2007) and

applied it on a developed application by the author of the study, whereas this thesis applies GGDA on available design software which is Revit Architecture.

This chapter also presented studies that concentrate on the benefits of BIM applications in the design process, but these studies have not focused comprehensively on the benefits of BIM applications in the conceptual design phase, and did not study the compability of these applications with different generative design approaches. In addition, the chapter reviewed some examples of firms that used Revit in their projects whether Revit was used t in all design phases or some of the design phases. The masses of the buildings of these examples were analyzed to their initial geometries to conceive the level of complexity that Revit Architecture is able to achieve.

Chapter 3. Methodology

The major goal of this thesis is to evaluate the abilities and limitations of Autodesk Revit Architecture in working on Initial Geometry Preparation (IGP) stage in Generative Geometric Design Approach (GGDA). The question of the thesis is; can the designers, who use GGDA, depend on Revit Architecture to work on IGP stage in GGDA?

In this thesis, designers who use GGDA will be aware of the compatibility of Revit Architecture with their approach. The knowledge of this compatibility helps them to know the design software that best suits their method of working. If the compatibility of GGDA is proved, it can positively affect the workflow of design process, because designers will be able to use Revit in all design phases without the involvement of other 3D modeling software. Working on Revit in all design phases achieves successful projects which are characterized by their commitment to the timetable and budget.

The methodology of this thesis examines focuses on the IGP stage of GGDA. This stage, as defined previously, is based on Initial geometries in configuring the design concept. The main reasons of concentrating on this stage are:

First, the IGP stage is the starting point of generating the design idea whether the idea was not sketched before, or was formulated in the designer's mind or his/her sketch.

Second, geometry is the basic unit for any design concept (Pottman et al. 2007, I). Figure 23 shows a three dimensional parametric model. That 3D model is based on the geometry of cube in its composition. While in Figure 24, the hexagon shape is the initial geometry for that deformed construction.

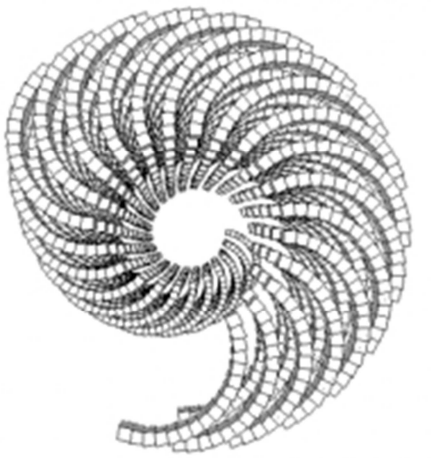


Figure 23: Cubic is the basic geometry of this parametric model[3].

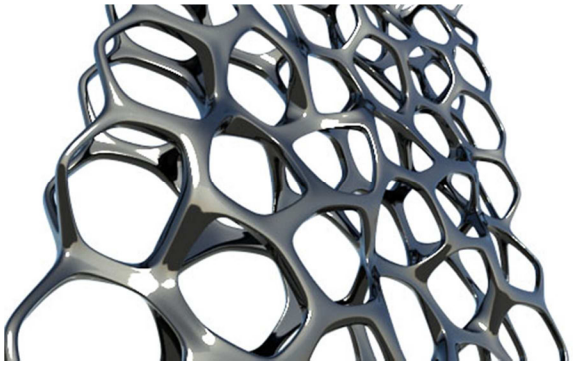


Figure 24: Hexagon shape is the initial geometry for this parametric deformed model[4].

Third, Revit doesn't have the default geometries that most 3D modeling softwares provide in their interfaces, such as 3Ds Max (Murdock 2009, 134-154) and Rhinoceros as well. This feature helps the designers with GGDA to save time and start working on GCT stage immediately without thinking of how these geometries can be created in that software.

[3] Ben Gray, "Rose Window- A 3D Parametric Model in Processing," Peer Produced Space, October 19, 2008, http://michalpiasecki.com/2008/10/19/rose-window-a-3d-parametric-model-in-processing/
[4] David Fano, "3Ds Max Tutorial - Modeling a Hexagon Screen," Design Reform, February 2, 2009, http://designreform.net/2009/02/3ds-max-tutorial-modeling-a-hexagon-screen/

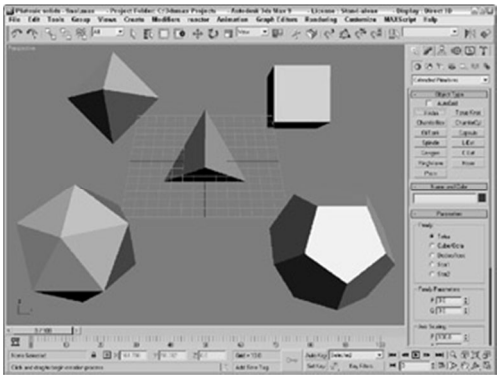


Figure 25: 3Ds Max software's primitive geometries (Murdock 2009, 139).

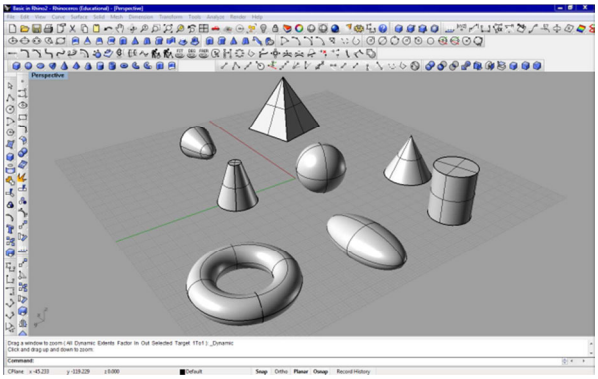


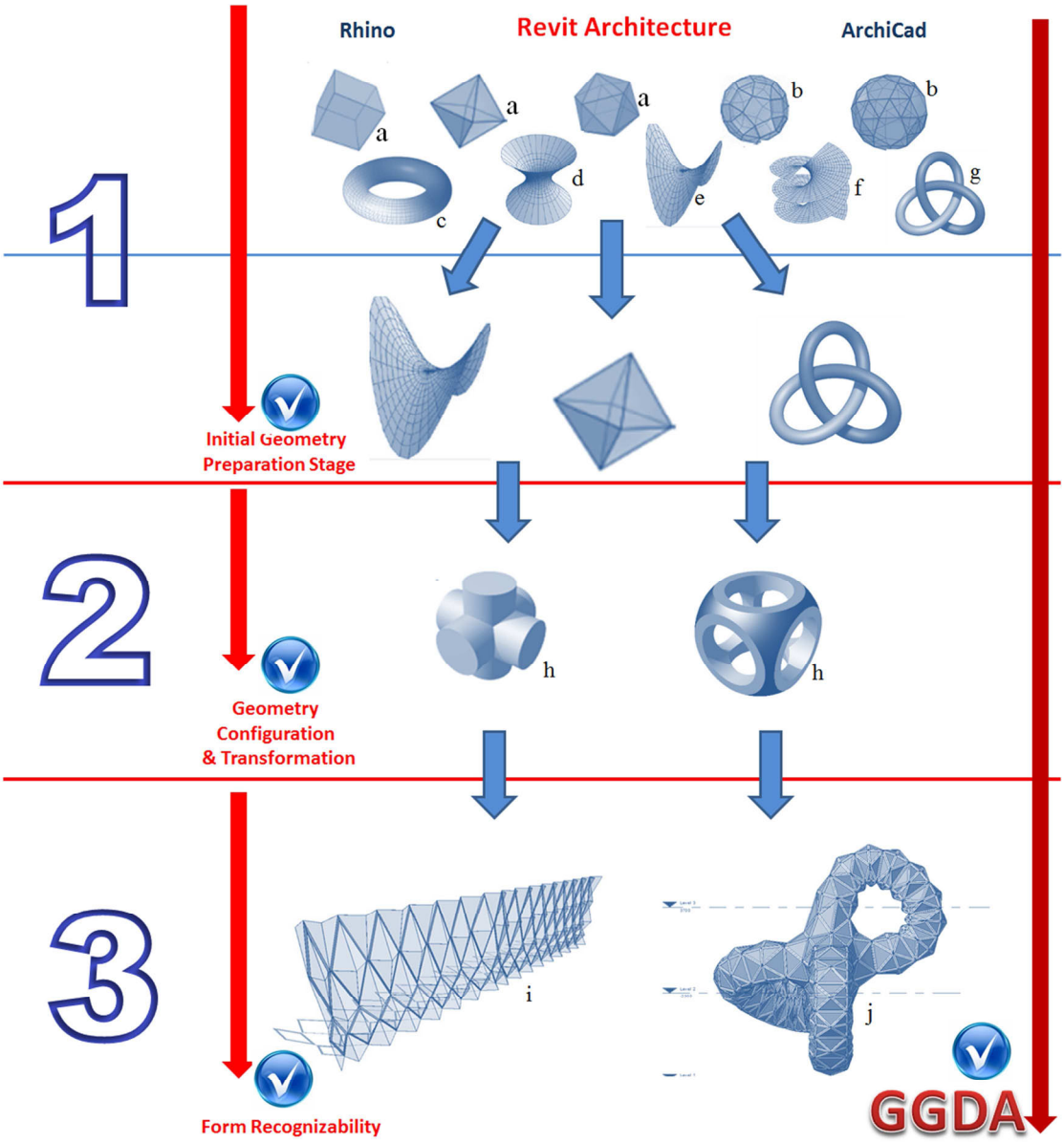
Figure 26: Rhinoceros software's basic objects.

3.1. The Process of Thesis's Methodology

The process of the thesis to achieve its goals is based on simulating of the IGP stage. This simulation process has two methods; *Main method*, and *Confirmation method*. In the main method, the researcher works on a series of experiments that create a selected set of geometries (solids and surfaces)[5]. In each experiment, one geometry is created. A selected number of the created geometries will be examined in the next stages of GGDA; GCT, and FFR. This examination contributes in testing the reliability of Revit in the entire process of GGDA. In the confirmation method, four volunteered students in Architecture College in University of Nebraska-Lincoln (UNL) create three selected geometries as a simulation of IGP stage only.

The next diagram shows the entire process of the simulation method of GGDA:

[5] See page 41.



a. "Platonic Solids," Wikipedia, http://en.wikipedia.org/wiki/Regular_solid
b. "Archimeadean Solids," Wikipedia, http://en.wikipedia.org/wiki/Archimedean_solid
c. "Torus," Wikipedia, http://en.wikipedia.org/wiki/Torus
d. "Hyperboloid," Wikipedia, http://en.wikipedia.org/wiki/One-sheet_hyperboloid
e. "Paraboloid," Wikipedia, http://en.wikipedia.org/wiki/Hyperbolic_paraboloid
f. "Helicoid," Wikipedia, http://en.wikipedia.org/wiki/Helicoid
g. "Trefoil Knot," Wikipedia, http://en.wikipedia.org/wiki/Trefoil_knot
h. "Constructive Solid Geometry," Wikipedia, http://en.wikipedia.org/wiki/Constructive_solid_geometry
i. Dave, " Revit Diamond Curtain Panel," deisgnreform, November 4, 2008, http://designreform.net/2008/11/hexagon-curtian-panels/
j. David Light, "More Topmod and Revit," Revit, November 19, 2008, http://autodesk-revit.blogspot.com/2008/11/more-topmod-and-revit.html

Diagram 1: The diagram shows the stages of GGDA that are followed in the main method.

3.2. Hypothesis

The hypothesis of the thesis is depending on the simulation process of the three stages of GGDA. Accordingly, the hypothesis is divided to four main steps. Each of these steps is split to a number of mini-steps. For example, the first step in the Table 1 is concerned to examine Revit with the first stage of GGDA. This step has six mini-steps that are concerned to create six categories of the selected geometries. If all these categories are created successfully in Revit Architecture, then this software is considered a reliable to work on IGP. This mechanism is applicable on the other three steps of the hypothesis. The validity of the hypothesis of this thesis is relies on the validity of each mini-steps. The hypothesis includes the following:

Hypothesis	Result
Autodesk Revit Architecture is able to create: • Preliminary solids. • Preliminary surfaces. • Secondary solids. • Secondary surfaces. • Complex solids. • Complex surfaces.	Autodesk Revit Architecture has the ability to work on ***Initial Geometry Preparation stage*** in GGDA.
Autodesk Revit Architecture is able to create all solids in: • Shorter time than Rhino and ArchiCAD. • Fewer steps and clicks than Rhino and ArchiCAD. Autodesk Revit Architecture is able to create all surfaces in: • Shorter time than Rhino and ArchiCAD. • Fewer steps and clicks than Rhino and ArchiCAD.	Autodesk Revit Architecture has ***Great ability*** to work on ***Initial Geometry Preparation stage*** in GGDA.
Autodesk Revit Architecture has the ability to create compound geometries.	Autodesk Revit Architecture is reliable to work on ***Geometry Configuration & Transformation Stage*** in GGDA.
Autodesk Revit Architecture has the ability to apply its components on all solids and surfaces.	Autodesk Revit Architecture is reliable to work on ***Form Recognizability Stage*** in GGDA.
Autodesk Revit Architecture is reliable to work with *GGDA*.	

Table 1: The hypothesis is depending on the simulation process of the three stages of GGDA.

3.3. Thesis Possible Outcomes

If the hypotheses of this thesis are proved, then valuable outcomes will arise. These outcomes will have a significant impact on the workflow of the design process, and on the designers who follow GGDA. The outcomes include the following:

Designers who use GGDA will believe in the reliability of Revit Architecture in configuring their conceptual ideas >This belief leads them to use Revit in all design phases> Using Revit in all design phases will significantly accelerate and smooth the work flow of the design process.

Conversely, if the hypotheses are not proved, other outcomes can be concluded:

- Revit Architecture is not compatible with GGDA> The designers who use that approach will look for other 3D softwares suits their way of thinking.

- The abilities of Revit Architecture are limited in limited generative design approaches.

- Revit Architecture has limitations, and more developments are needed for this software to overcome these limitations.

3.4. The Elements of Methods' Experiments

The main and the confirmation methods of the simulation process in the methodology of this thesis have important and shared elements. These elements build the structure of the experiments that are implemented in the both methods. They are presented in the geometries that are created in the experiments, and the variables are considered before and after the experiments. These elements should be clarified and explained to the readers first before the sections of the main and confirmation methods, because they are shared between the two methods and should be understood by the readers carefully. The elements include the following:

3.4.1. The Geometries

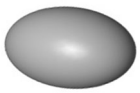
The chosen geometries are based on complexity standard: preliminary, secondary and complex geometries. The selected geometry in this thesis, were divided into two main categories: Solids, and Surfaces.

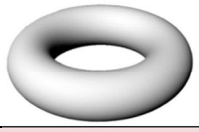
Each category is split into three subcategories. For instance, solid category is divided to: preliminary solids, secondary solids, and complex solids.

3.4.1.1. The Selected Geometries:

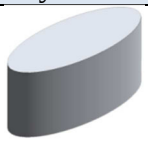
a) Solids:

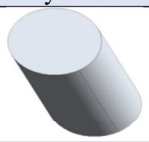
Preliminary solids:

Sphere	Cone	Prism	Pyramid	Cylinder	Ellipsoid
					

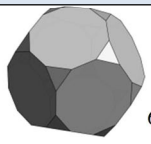
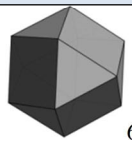
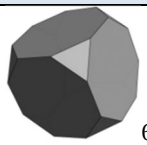
Torus	Tetrahedron
	

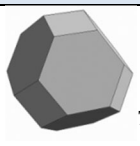
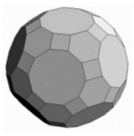
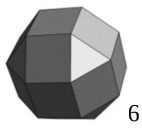
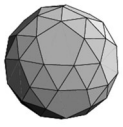
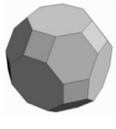
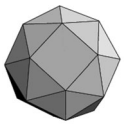
Secondary Solids:

Octahedron	Dodecahedron	Anti-Prisms	Truncated Cone	Elliptic Cone	Elliptic Cylinder
					

Oblique Circular Cone	Right Circular Cone	Oblique Circular Cylinder
		

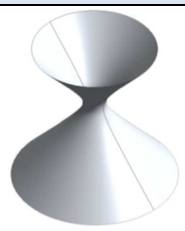
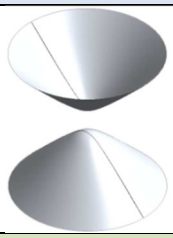
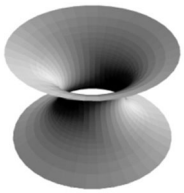
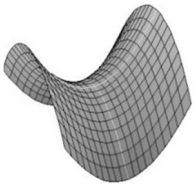
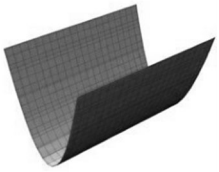
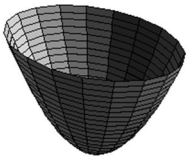
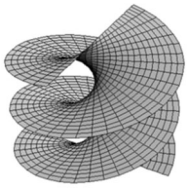
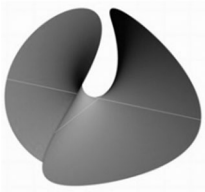
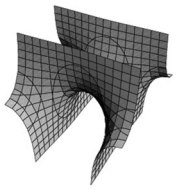
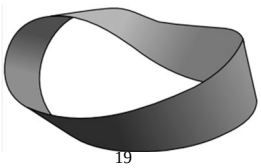
Complex Solids:

Ices Dodecahedron	Truncated dodecahedron	Truncated Tetrahedron	Cub Octahedron	Truncated Icosahedron	Truncated Cube
 [6]	 [6]	 [6]	 [6]	 [6]	 [6]

Truncated Octahedron	Truncated Icosi dodecahedron	Rhombi cub Octahedron	Snub Dodecahedron	Truncated Cub octahedron	Snub Cube
 [7]	 [6]	 [6]	 [8]	 [6]	 [9]

[6] Craig Kaplan, "Symmetrohedra," University of Waterloo, February 6, 2005, http://www.cgl.uwaterloo.ca/~csk/projects/symmetrohedra/ (accessed December 11, 2010).
[7] George W. Hart, "Zonohedrification," Georgehart, http://www.georgehart.com/zonohedra/zonohedrification.html (accessed December 11, 2010).

b) Surfaces:

Preliminary Surfaces:				
Hyperboloid One Sheet	Hyperboloid Two Sheet	Paraboloid	Catenoid	Helical Surface
			 [10]	 10
Secondary surfaces:				
Hyperbolic Paraboloid	Hyperbolic cylinder	Parabolic Cylinder	Elliptic Paraboloid	Helicoid
 [11]		 [12]	 [13]	 [14]
Complex surfaces:				
Enneper Surface	Scherk Surface	Klein Bottle	Trefoil Knot	Mobius Strip
 15	 16	 17	 18	 19

[8] Eric Weisstein, "Snub Dodecahedron," Wolfram MathWorld, 2011, http://mathworld.wolfram.com/SnubDodecahedron.html (accessed December 11,2010).
[9] Eric Weisstein, "Snub Cube." Wolfram MathWorld, 2011, http://mathworld.wolfram.com/SnubCube.html
[10] Francisco Martin, "Classical minimal surfaces," Granada University, http://www.ugr.es/~fmartin/dibujos-clasicos.htm (accessed December 11,2010).
[11] Department of Mathematics, Asheville-Buncombe Technical Community College, http://abtech.edu/as/mat/default.asp (accessed December 11,2010).
[12] Kevin P. Rice, "Are Cylinders Round?" 2011, http://freightyard.net/papers/cylinder/ (accessed December 11,2010).
[13] Eric W. Weisstein, "Elliptic Paraboloid," Wolfram MathWorld, 2011, http://mathworld.wolfram.com/EllipticParaboloid.html (accessed December 11,2010).
[14] "Helicoid," Wikipedia, http://en.wikipedia.org/wiki/Helicoid (accessed December 11,2010).
[15] "The Enneper surface," Indiana University, http://www.indiana.edu/~minimal/maze/enneper.html (accessed December 11,2010).
[16] Eric W. Weisstein, "Scherk's Minimal Surfaces." Wolfram MathWorld, 2011, http://mathworld.wolfram.com/ScherksMinimalSurfaces.html (accessed December 11,2010).
[17] Davide P. Cervone, "Glass Klein Bottle," Union College, September 8, 2001, http://www.math.union.edu/~dpvc/professional/art/Asaro.html (accessed December 11,2010).
[18] "Trefoil knot," Wikipedia, http://en.wikipedia.org/wiki/Trefoil_knot (accessed December 11,2010).

Secondary geometries are the children of the preliminary geometries, and have an increased level of complexity. They are consisted of one to more of preliminary geometries and have specific names in mathematics, such as Octahedron. Complex geometries are composed of preliminary and secondary geometries, and have also certain names in mathematics, such as Icosi dodecahedron.

3.4.2. The Variables:

It is important for research to clearly identify and carefully study the appropriate variables, especially the researches that contain experiments. Variable is defined as*:" any entity that can take on different values*." (Social Research Methods 2006, Variables).
In other words, variables are any factor that has different quantities or qualities. Variables are divided into two types: Independent variables, and Dependent variables. More discussion and details about the variables can be found in the next sections.

[19] "Hair Band clip art," Clker, http://www.clker.com/clipart-24184.html (accessed December 11,2010).

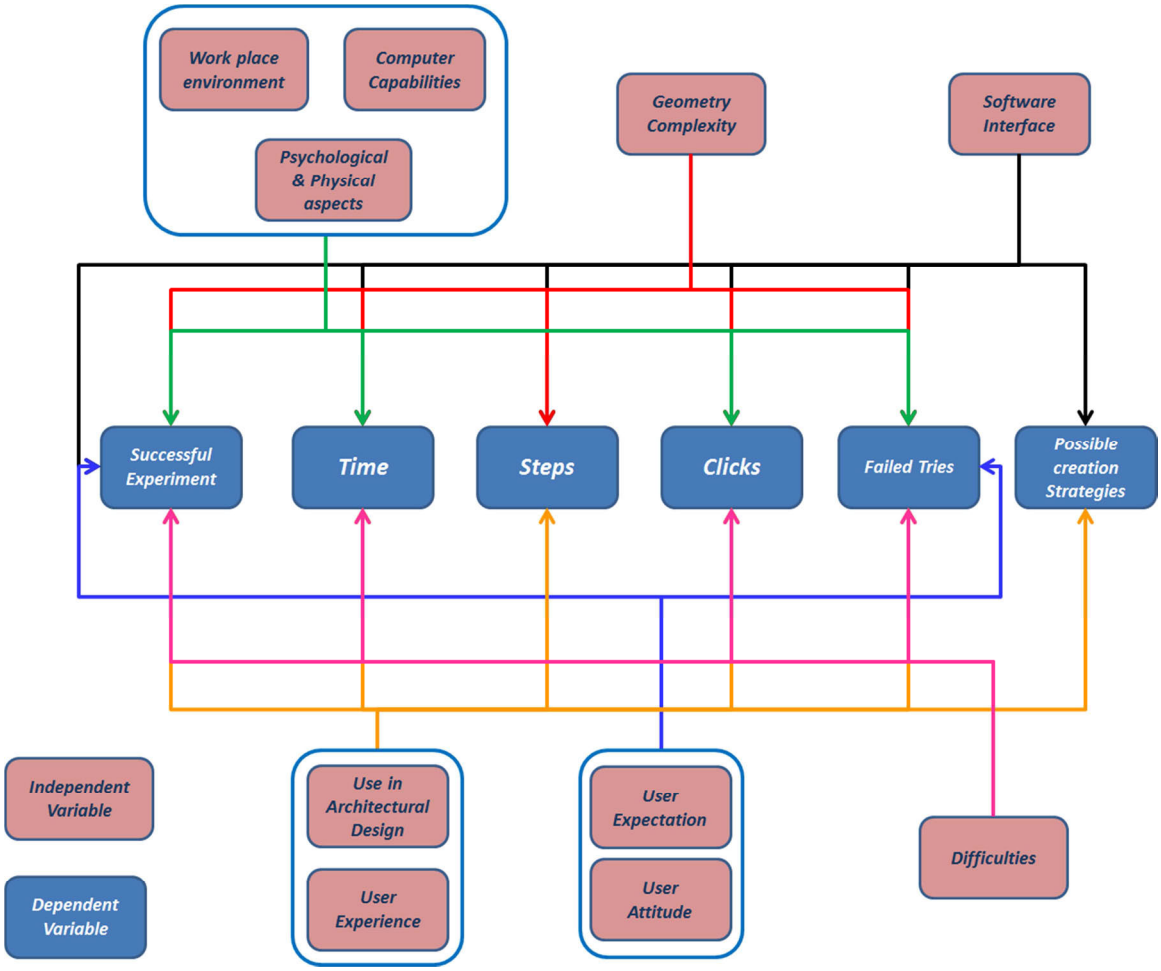


Diagram 2: The correlation between the independent variables and the dependent variables.

3.4.2.1. Independent Variables:

The independent variable (IndV) is defined as "*what you (or nature) manipulates -- a treatment or program or cause*." (Social Research Methods 2006). In this thesis, there are four categories of the independent variables:

a) User's variable:

- Previous experience
- Attitude
- Psychological and physical statue,
- Expectation.

b) The environment of workplace.

c) Technical variables:

- Computer's capabilities
- Software’s interface.

d) Faced difficulties.

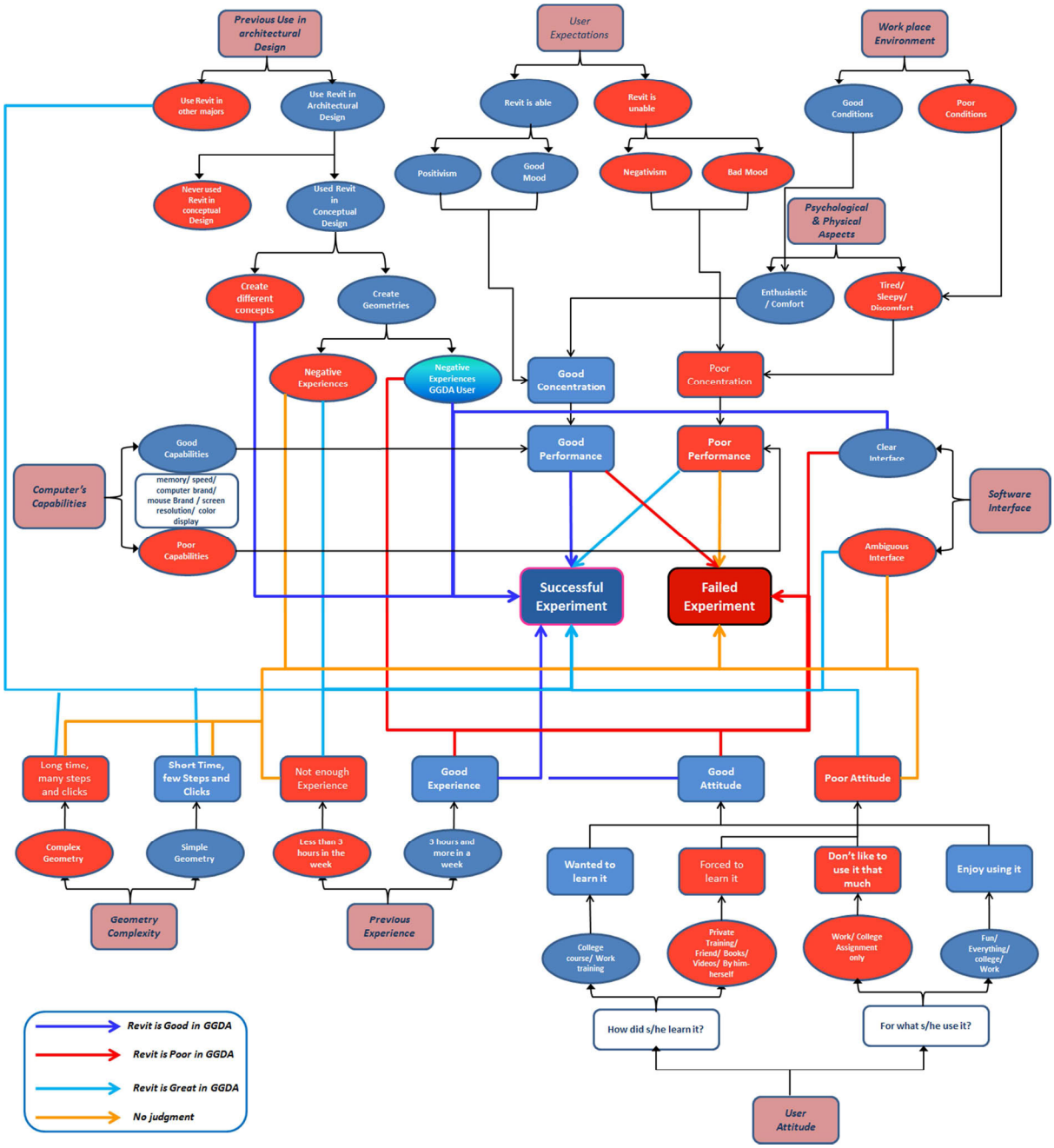


Diagram 3: The correlation between independent variables and the Success/Failure of the experiments.

3.4.2.1.a. User's variables:

i. **User Experience** (Despont-Gros et al. 2004, 251)**:** The experiences of using computers in general and the use of particular softwares have an impact on the success and the work speed within the experiments. This experience ranges to: the general experience of using computers, the general experience of using specific design softwares, the user's experience of using these softwares in conceptual design phase, and finally the user's experience of using them with GGDA (See Diagram 4).

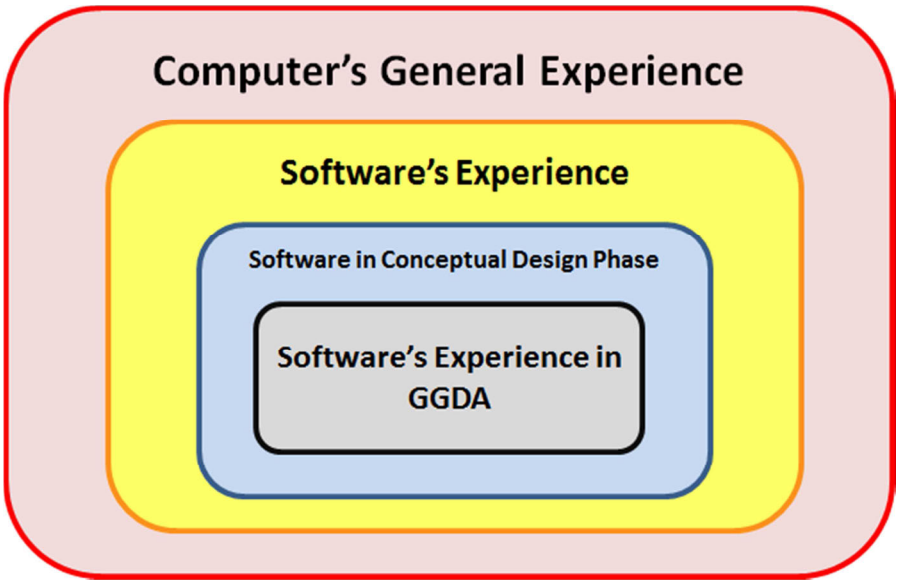


Diagram 4: The levels of experience.

The correlation between user's experience and the success of the experiment is a positive correlation. If the user has good experience in using the softwares, the potential of the experiment's success increases. While the correlation between the

experience and experiment's time is negative. Users with high level of experience spend less time working on the softwares. These correlations are tested in the simulation process in this thesis.

ii. **User's Attitude** (Despont-Gros et al. 2005, 251): The attitude of the user means her/his willingness of using the software. This attitude can be determined by the way that the user learned how to use the software: Did s/he want to learn it? Or was s/he required to learn it by individual, college or company? Other way to determine the user's attitude is the extent of using the software: Does s/he use it only to work on assignments or job's tasks? Or does s/he use it most of the time and achieve personal business? The correlation between the experiment's success and user's attitude is positive correlation as well.

iii. **Psychological and Physical Statue of the User:** The physical and psychological aspects also have an impact on user's performance. If the user is tired, exhausted or frustrated in the time of the experiment, her/his performance will be negatively affected. It reduces the concentration of the user on her/his work which might cause long time to accomplish the task. It might also cause a decrease in her/his attitude. These results could lead to the failure of the experiment.

iv. **User's Expectations** (Despont-Gros et al. 2005, 252): The expectation of the user is considered one of the variables that affect the results. The optimistic feeling

towards the results of the experiment will help to achieve the goals of the user. It also applies to the negative feelings.

v. **Work Place's Environment** (Despont-Gros et al.2005, 250): The surrounding environment of work place also affects the performance of the user and the success of the experiment. A work place with good lighting (Chiemeke et al. 2007, 3), proper temperature, convenient space (Despont-Gros et al. 2005, 251), comfortable colors, and quiet atmosphere has a positive impact on the psychological and physical aspects of the user.

3.4.2.1.b. Technical Variables:

i. **Computer Capabilities:** The technical specifications of the used computer in the experiment play a significant role in user's performance and the success of the experiment (Vanier1985, 10). These specifications include the capacity of the memory, computer's speed, computer's brand, mouse's brand, screen resolution and screen display colors (Vanier1985, 10; Calderon et al. 2000, 5). High-tech specifications will positively affect the performance of the user, the software, the speed and the success of the experiment. Here are the standard specifications (College of Architecture, 2011) of computers that could be used for design work:

Hardware Specifications (PC)	Hardware Specifications (MAC)
• CPU: Intel or AMD 2.33ghz Core 2 Duo or faster. • Display: 15" WXGA+ minimum (1440x900 minimum). • RAM: 4 GB minimum. • Disk Storage: 250 GB minimum. • External Mouse: 3-button with scroll wheel required Video Card: 256mb DirectX 10 supported adapter from the following series: - ATI Radeon HD 37xx NVidia GeForce 8800 - ATI Radeon HD 48xx NVidia GeForce 9400. - ATI Radeon HD 56xx NVidia GeForce 470M. ATI FireGL series NVidia Quadro Series. • Operating System: MS Vista or Windows 7 Enterprise/Ultimate required	• CPU: MacBook Pro 2.33ghz Core 2 Duo or faster. • Display: 15" WXGA+ minimum (1440x900 minimum). • RAM: 4 GB minimum. • Disk Storage: 250 GB minimum. • External Mouse: 3-button with scroll wheel required. • Video Card: 256mb DirectX 10 supported adapter from the following series: - ATI Radeon HD 37xx NVidia GeForce 8800 - ATI Radeon HD 48xx NVidia GeForce 9400 - ATI Radeon HD 56xx NVidia GeForce 470M - ATI FireGL series NVidia Quadro Series. • Operating System: OS X 10.5/6 w/ Vista Enterprise BootCamped

Table 2: The standard specifications of Architecture College in UNL (College of Architecture, 2011).

ii. **Software's Interface** (Despont-Gros et al. 2005, 252; Odeh and Adwan 2009, 1061)**:** The interface has an important impact on the performance of the user, and the ease of using the software. Poor user interface is considered a constraint in working on the software. For instance, the long command sequence and the ambiguity of icons and commands increase the number of work hours and disable the work flow. The basic elements that characterize software's interface are:

terminology, screen design, navigation, (Despont-Gros 2005, 249) customization, input, help information, training, command sequence and colors.

3.4.2.1.c. Faced difficulties:

In each creating experiment, there are difficulties that might be faced. These difficulties could affect the time and number of steps and clicks of the experiment. They could lead also to the failure of the experiment, which might be considered a limitation in the software.

3.4.2.2. Dependent Variables:

The dependent variable (DepV) is defined as "*what is affected by the independent variable - your effects or outcomes*."(Social Research Methods 2006). For these experiments, the dependent variables are: *Steps, Clicks, Time, Number of created geometries* (Devon et al. 2007, 229), *Failed tries, and Possible strategies.*

a) **The Results of the Experiment*:*** The result of the experiment is the most important DepV that be observed. The number of successful experiments affects the result of the thesis by confirming the ability of Revit Architecture in creating the geometries in IGP stage (Despont-Gros et al. 2005, 246), and that applies also on the failed experiments. IndV should be considered in the analysis of experiment's results. For instance, if the experiment was failed, the IndVs are regarded to figure out if they might affected the experiment's results negatively,

and leaded to the failure. According to this process, the final decision about the result of each experiment can be taken.

b) **Time** (Devon et al. 2007, 229; Vanier1985, 20): is counted and recorded as: hours, minutes, seconds by using a digital stop watch (Figure 27), and the software recorder. The time of creating each geometry in Revit is compared with the time spent on other two different softwares. These two softwares are discussed in detail in the comparative tools section. Time of experiment is affected by all independent variables listed before. These variables are considered in time comparing process to ensure accurate results.

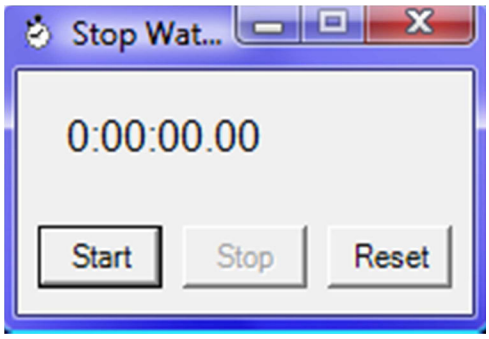


Figure 27: Used digital Stopwatch.

c) **Steps of Creation Process:** The commands that the user follows in each successful experiment of creating geometries are counted and documented. The process of geometry's creation is recorded using a software recorder (Figure 28). The recording helps in defining the main steps in creating each geometry.
The recorder software records all experiments whether they are successful or failed. Only successful experiments will be counted and documented.

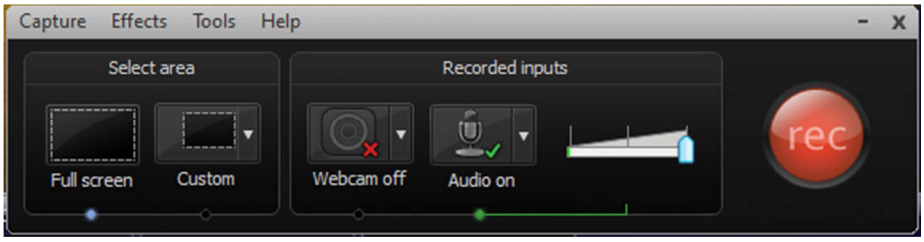


Figure 28: The used Software Recorder.

d) **Clicks of Creation Process** (Zulch and Stowasser 2000, 4; Odeh and Adwan 2009, 1064)**:** The number of clicks that a user makes during the experiment is also counted. They are counted using RUI application (Figure 29) which counts key strokes and mouse clicks and moves. There are several factors that impact the resulted number of clicks. These factors include: user's experience of using the software, the physical and psychological state of the user, software's interface, the surrounding environment, computer's technical specifications and geometry's complexity. These factors are taken into account in data analyzing phase to avoid bias and inaccurate results.

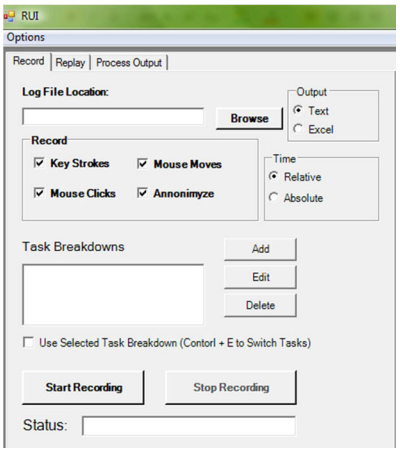


Figure 29: Software counter of clicks.

e) **Number of Created Geometries:** The number of created geometries is an important factor to judge the software. If a large number of geometries were created in Revit comparing with other two softwares, then Revit is capable to work on the IGP stage. The percentage is calculated at the final stage of the methodology.

f) **Number of Trials** (Odeh and Adwan 2009, 1064-1065)**:** ***Trial*** means in this thesis the attempt that the user tries to create the geometry in the experiment, and it could be successful or failed, whereas ***Experiment*** means the process of creating one geometry in one software. For instance, the creation process of generating the sphere in Revit is considered an experiment. The experiment may contains more than one trial, and the number of trials is important in the analysis process because it demonstrates the difficulties that the user faced during the experiment and also displays the time that was spent to finish the experiment. Diagram 5 illustrates the table of the collected data in Appendix B, and explains the function of each column and row in that table.

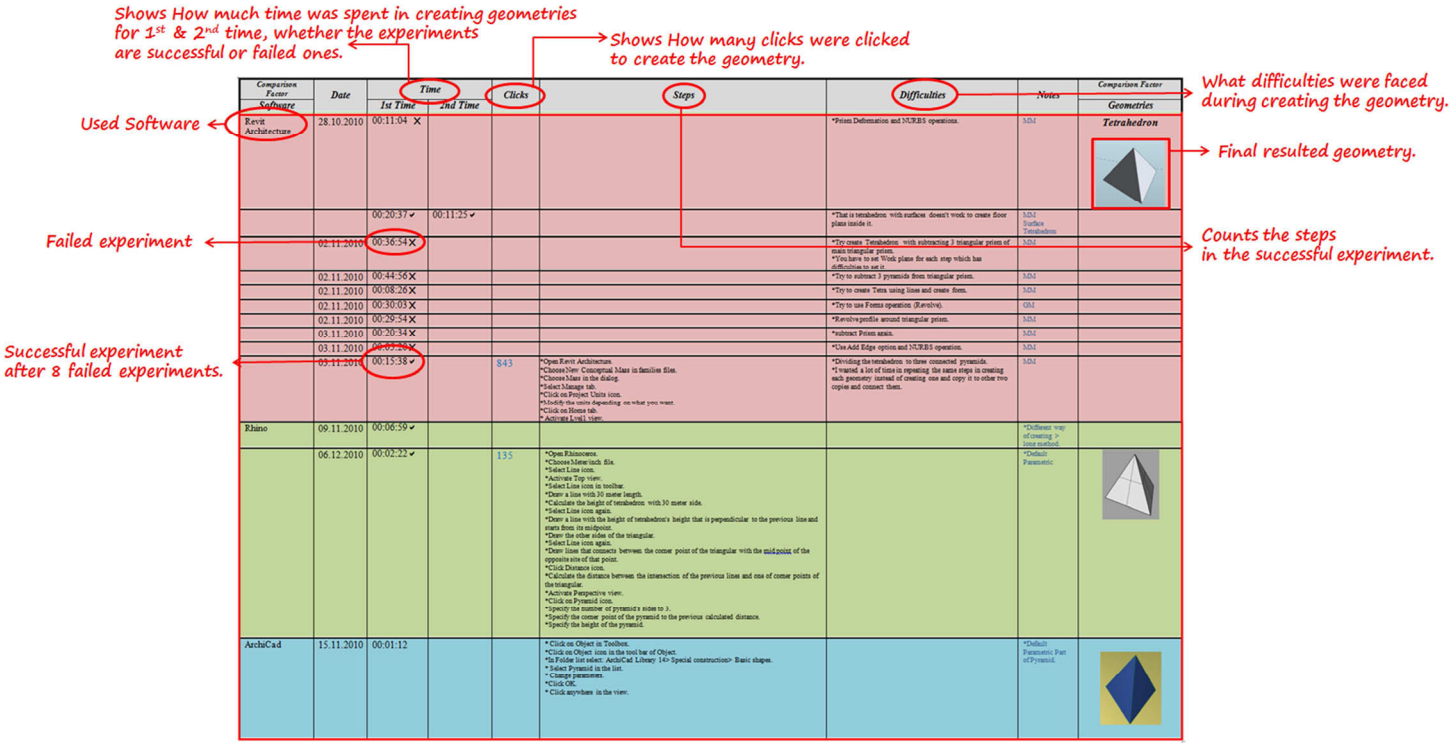


Diagram 5: This is an explanation of methodology criteria table in Appendix B.
This table contains all data of the experiments.

3.4.2.3. Comparative Tools (Softwares)

The comparative tools are the factors that help in analyzing the results. There are two comparative tools in the sub-methods: ***Rhinoceros*** and ***Graphisoft ArchiCAD***. The two softwares are examined as well with the same experiments. The experiments have the same variables and the same geometries. The selected softwares were chosen depending on specific aspects, to achieve a fair comparison, and avoid prejudice and bias. These aspects include: *Category*, *Massing abilities*, *Popularity* and *Produced Company*. Table 3 shows these aspects.

Software	Category	Massing Abilities	Popularity	Company
Rhinoceros	Not BIM application.	Known massing abilities.	Popular in USA.	Not Autodesk. McNeel Co.
ArchiCAD	BIM application.	Unknown massing abilities.	Not Popular in USA.	Not Autodesk. Graphisoft Co.

Table 3: Shows the aspects of the selected softwares.

3.5. Main Method

In the main method, the researcher simulates the three stages of GGDA on the entire set of geometries on Page 41. This simulation is done by the three softwares: Revit Architecture 2011, Rhinoceros 4.0, and ArchiCAD 14.

The following table shows the used hardwares and softwares in the main method:

Hardware	Software	Hardwares and softwares for Recording the process of Experiment
• **Computer model:** HP Pavilion dv7 Notebook PC • **Processor:** Intel (R) Core (TM) Quad CPU Q 9000 @ 2.00 GHz 2.00 GHz • **Display:** 1600X900 • Memory: 6.00 GB • **Disk Storage:** 450 GB • **System type:** 64-bit Operating System • **Window Edition:** Window Vista Home Premium • **Web Camera:** HP MediaSmart Webcam 2.1.1.11.24 • **Video Card:** Generic PnP monitor - ATI Mobility Radeon HD 4650 - ATI Radeon Graphics Processor (0X9480) • **Speakers & Microphone:** IDT High Definition Audio CODEC • Mouse driver: Synaptic PS/2 Port TouchPad • **Mouse brand:** Microsoft and Logitech 3-button with scroll wheel.	• Autodesk Revit Architecture 2011 x64, 2010 (Student version). • Rhinoceros 4.0 SR5b, 2009 (Educational). • ArchiCAD 14.0.0 x86 (Educational).	• Web Camera: HP MediaSmart Webcam 2.1.1.11.24 • Speakers & Microphone: IDT High Definition Audio CODEC. • Camtasia Studio 6.0.3, 2009. • Stopwatch application.

Table 4: Shows the used hardwares and softwares in main method.

3.6. Hypothesis of the Main Method

The methodology examines Revit Architecture, Rhinoceros and ArchiCAD, in order to verify the hypothesis of the thesis progressively. The hypothesis of the main method examines the softwares in all stages of GGDA[20].

Hypothesis	Result
Autodesk Revit Architecture is able to create: • Preliminary solids. • Preliminary surfaces. • Secondary solids. • Secondary surfaces. • Complex solids. • Complex surfaces.	Autodesk Revit Architecture has the ability to work on ***Initial Geometry Preparation stage*** in GGDA.
Autodesk Revit Architecture is able to create all solids in: • Shorter time than Rhino and ArchiCAD. • Fewer steps and clicks than Rhino and ArchiCAD. Autodesk Revit Architecture is able to create all surfaces in: • Shorter time than Rhino and ArchiCAD. • Fewer steps and clicks than Rhino and ArchiCAD.	Autodesk Revit Architecture has ***Great ability*** to work on ***Initial Geometry Preparation stage*** in GGDA.
Autodesk Revit Architecture has the ability to create compound geometries.	Autodesk Revit Architecture is reliable to work on ***Geometry Configuration & Transformation Stage*** in GGDA.
Autodesk Revit Architecture has the ability to apply its components on all solids and surfaces.	Autodesk Revit Architecture is reliable to work on ***Form Recognizability Stage*** in GGDA.
Autodesk Revit Architecture is reliable to work with *GGDA*.	

[20] See pages 3-5.

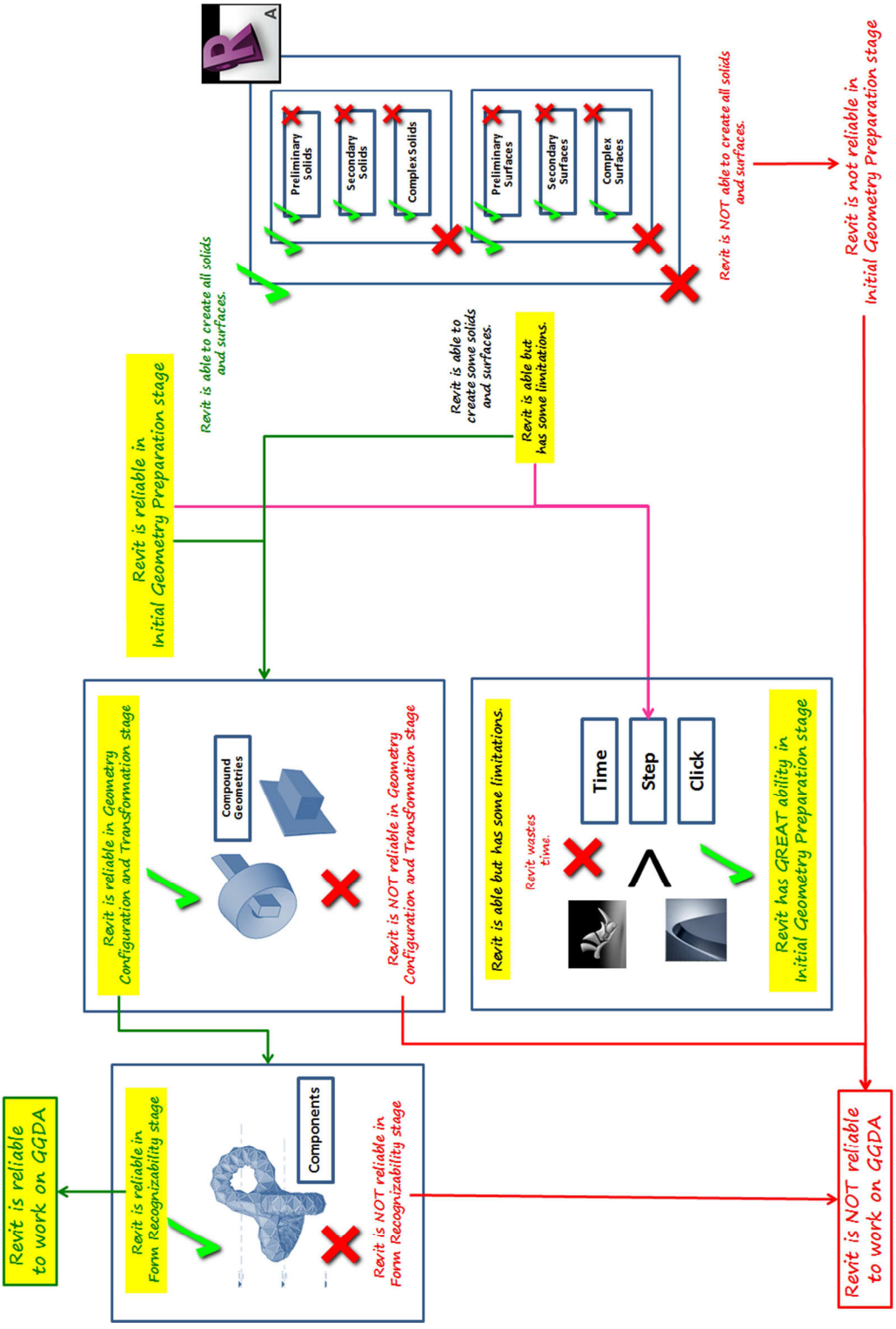


Diagram 6: Shows hypothesis's steps to discover the abilities and limitations of Revit Architecture.

3.6.1. Autodesk Revit Architecture 2011

3.6.1.1. Initial Geometry Preparation Stage in Revit Architecture

This section describes the steps that were followed to work on Revit in IGP stage in GGDA. In this stage, a set of initial geometries is created gradually that is included on page 41. The methodology first, examines the creation of solid geometries with its different categories: preliminary, secondary and complex solids. In the next step, surface's categories are created.

During these experiments, time, steps and clicks are counted in creating each geometry. Stopwatch software and Camtasia Recorder software are used in time counting and steps recording. Clicks are counted manually in all experiments in the main method because the researcher couldn't obtain a counter clicks software in the first period of the research. The time, steps and clicks are documented with detailed comments in the Appendix B. The appendix includes a table that documenting the repeated experiments for each geometry, and the difficulties that the researcher faced during each experiment. This chapter explains some of these experiments in details for each used software.

3.6.1.2. About Autodesk Revit Architecture 2011

Autodesk Revit was issued in 2002 (Eastman et al. 2008, 57) by Autodesk company. It is considered Building Information Modeling (BIM) software. It specializes in AEC industry. It has three main products: Revit Architecture, Revit Structure, and Revit MEP.

Revit Architecture 2011 is the latest version; that version is evaluated in this thesis. New enhancements (Kygriel et al. 2010, 255) have been added to this version especially for creating design ideas.

3.6.1.3. New families

New family's files have been added to the original massing file *Conceptual Mass Model Family* (MMF). These families include: *Adaptive Component Family* (ADF), *Generic Model Family* (GMF). In the ADF file, the user can modify the shape of curtain wall edges after she/he applies it to a mass. GMF file has other generic files. The main GMF file is specialized to create special forms and geometries. These forms are created by using special operations in Forms panel that MMF doesn't have. The panel includes Extrusion, Blend, Revolve, Sweep, Blend, Swept Blend, and Void Forms operations. The created forms in that file can be loaded to *Project File* (PF) and MMF file not vice versa. Also, the masses are created in MMF file can be loaded only to PF file and not vice versa. Edit Family option in Model panel is used to edit any loaded family in PF file and MMF file.

The forms that were created in GMF file can be loaded to PF file directly, but they are useless there. These forms are considered generic models in PF file. Generic models cannot be used as Mass models in PF file. The user can only apply wall, roof, and curtain wall components on the Generic models but cannot apply Mass. The only way to use GMF forms, is to load them first to MMF, then load them to PF. This loading process

will cost more time in the design process. Diagram 7 demonstrates the loading process among Revit Architecture's files.

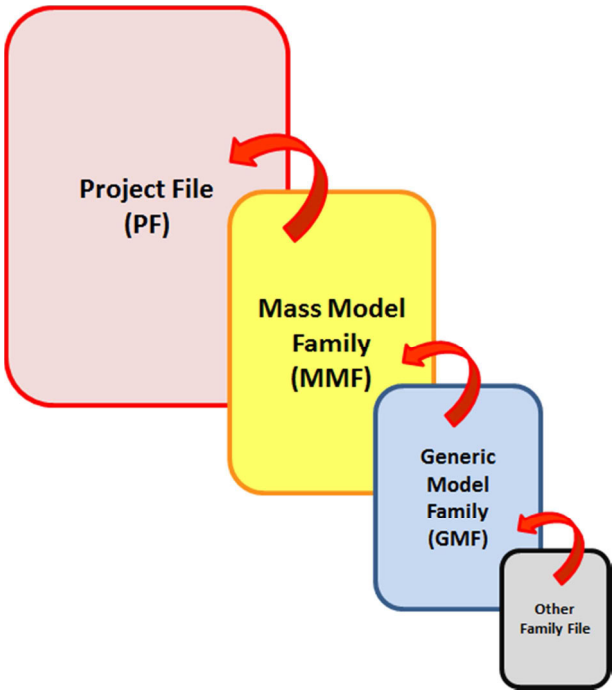


Diagram 7: The hierarchy of loading different files in Revit Architecture.

The main method focuses on three main files: PF, MMF, and GMF files. The basic units for all experiments in that method are meters. Using meter unit creates masses that have real building scale. To modify the unit system of any Revit file, follow the path described: *Manage tab> Project units*.

3.6.1.4. The Experiments of Solid geometries in Revit Architecture

This section illustrates some examples of solid geometries experiments in Revit Architecture. It cannot contain the explanation of all the experiments. Therefore, Appendix B on page 173 includes all the information about them.

3.6.1.4.a. Preliminary Solids in Revit Architecture

3.6.1.4.a.i. Sphere

Sphere as defined mathematically in Wolfram MathWorld is: "*the set of all points in three-dimensional Euclidean space* $\mathbb{R}^3$ *that are located at a distance* r *(the "radius") from a given point (the "center"). Twice the radius is called the diameter, and pairs of points on the sphere on opposite sides of a diameter are called antipodes.*"[21] (Weisstein 2011)

Figure 30: Sphere in Revit.

In Revit, the sphere was created successfully in two different families with two different methods (Figure 30). It was created in MMF, and GMF. The two resulted spheres can be loaded to Project File (PF). However, it is preferable in Revit to create the mass on MMF, because it saves time according to long loading process from GMF to PF. In addition, GMF has limited options. It misses some of MMF options such as 3D snapping, Create Form, etc. Therefore the created geometry in that file may need more improvements in MMF file before loading it to PF.

21 Eric Weisstein, "Sphere," Wolfram MathWorld, 2011, http://mathworld.wolfram.com/Sphere.html

The experiment was achieved in **fifteen** steps at a time of no more than **fifty three seconds**.

3.6.1.4.a.ii. Prism

SpringerLink mathematical encyclopedia defined Prism as: "*a polyhedron for which two sides are n-gons (the bases of the prism), while the other n sides (the lateral sides) are parallelograms. The bases are congruent and located in parallel planes. A prism is called direct if the planes of the lateral sides are orthogonal with the planes of the bases. A direct prism is called regular if its bases are regular polyhedra. A prism is called triangular, rectangular, etc., depending on whether the bases are triangular, rectangular, etc.... The volume of a prism is equal to the product of the area of one of its bases and its height (the distance between the bases).*" [22] (SpringerLink 2001)

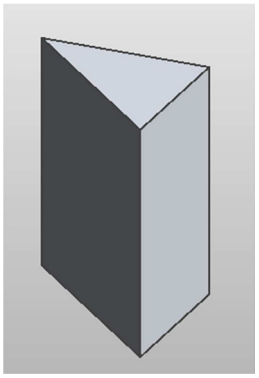


Figure 31: Prism in Revit Architecture.

Prism was created successfully in MMF (Figure 31). It was created twice with the same method and steps. The reason of repeating the experiment is to determine the effect of the first experiment on the speed of the second experience. It was observed that the second

[22] Encyclopedia of Mathematics, " Prism," SpringerLink, 2001, http://eom.springer.de/P/p074830.htm

trial was faster than the first, because of the prior knowledge of the steps. Here are the times of the 1st and 2nd experiments:

1st trial: (Time= 00:01:16)

2nd trial: (Time = 00:00:42)

The first experiment was completed in **fourteen** steps at **a minute and sixteen seconds**, whereas the second trial was achieved in **fourteen** steps, **thirty four** clicks and **forty two seconds**.

3.6.1.4.a.iii. Cylinder

Wolfram MathWorld defined Cylinder mathematically as: "*a solid bounded by a closed generalized cylinder, and two parallel planes.*"[23](Weisstein 2011)

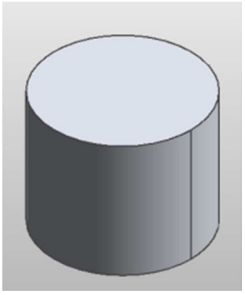


Figure 32: Cylinder in Revit.

Cylinder was created twice successfully in Revit, with the same method (Figure 32). Unfortunately, the first trial wasn't recorded, and cannot be repeated. The time can be guessed **approximately as minute,** whereas the second trial lasted for only **twenty four** seconds.

[23] Eric Weisstein, "Cylinder," Wolfram MathWorld, 2011, http://mathworld.wolfram.com/Cylinder.html

The experiment of creating a cylinder was done in MMF in **fourteen** steps and **twenty one** clicks. It has the similar steps of creating the sphere as shown in Appendix B, except the last step where Revit gives two options; cylinder, and Sphere as shown in Figure 33. Cylinder option is chosen this time.

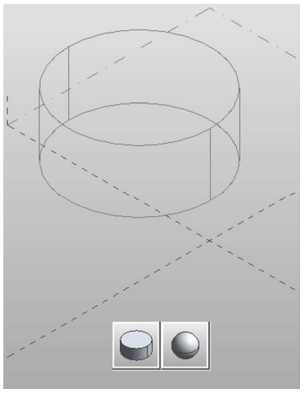


Figure 33: The two option that Revit offers.

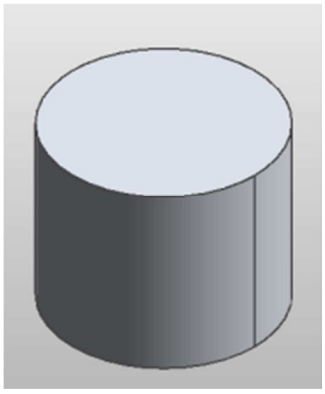


Figure 34: The resulted Cylinder in MMF.

3.6.1.4.a.iv. Cone

Cone as defined mathematically is: "a *geometric figure swept out by a line (generator) that joins a point moving in a closed curve in a plane, to a fixed point (vertex) outside the plane. In a right circular cone, the vertex lies above the centre of a circle (base), and the cone's generators join the vertex to points on the circle."*[24]

Figure 35: Cone in Revit.

[24] "Cone." World Encyclopedia, http://www.encyclopedia.com/topic/cone.aspx#3

Cone was created four times in Revit (Figure 35). The first trial was in GMF file. It was a failed trial and took **thirteen minutes** of time. The second trial was also in GMF. It was a successful and lasted **three minutes** and **fifty five seconds** with about **ten** steps. On the other hand, the third trial was created in MMF. It was also successful, and lasted **a minute** and **thirty seconds** with **seventeen** steps and **forty seven** clicks .Although, the last trial was successful and the fastest one in time, the created geometry was useless in PF file. The geometry was created as mesh. Mass Floors option in PF file works only on solid geometries to create floors not on meshes. Figure 36 and Figure 37 shows the final step of creating the cone and the resulted geometry in Revit Architecture.

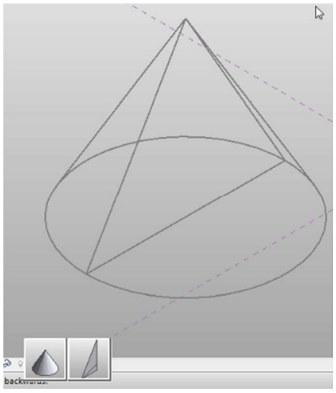


Figure 36: The two options that Revit offers in MMF.

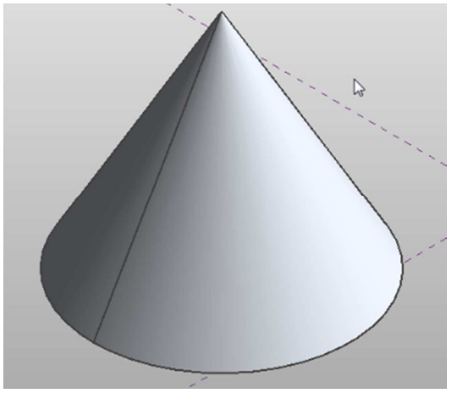


Figure 37: The resulted cone in MMF.

3.6.1.4.b. Secondary Solids in Revit Architecture

3.6.1.4.b.i. Anti-Prism

SpringerLink mathematical encyclopedia defined Anti-Prism as: "*a semi-regular polyhedron in which two parallel faces are congruent regular, while the remaining faces are regular triangle*."[25] (SpringerLink 2001)

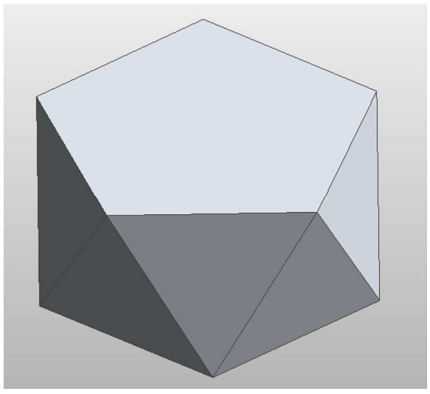


Figure 38: Anti-Prism in Revit.

Anti-Prism was created four times in Revit Architecture. The researcher spent about three hours work on the first two tries, but they were unsuccessful. The third try was successful (Figure 38). It lasted only **thirty one minutes** and **forty three seconds** with **fifty seven** steps and **1382** clicks. The researcher in that third try used options that she didn't use before as **Add Edge** command in **Form Element** panel in **Modify/Form** tab as illustrated in Figure 39. That command made the process of creating Anti-prism easier. The fourth try was an experiment to determine the effect of the third successful experience on the time of the fourth one.

[25] Encyclopedia of Mathematics, " Anti-prism," SpringerLink, 2001, http://eom.springer.de/A/a012680.htm

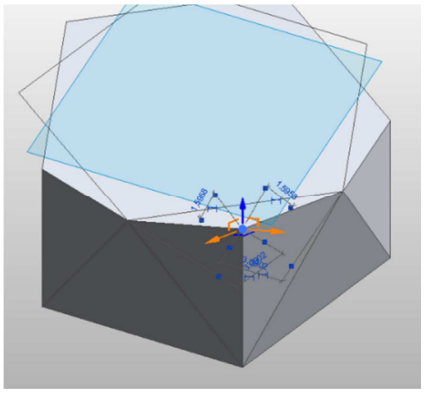


Figure 39: Add Edge command and Drag vertexes helped in creating Anti-Prism geometry.

3.6.1.4.b.ii. Octahedron

Octahedron as defined in SpringerLink mathematical encyclopedia is: "*a solid figure having eight triangular faces, twelve edges and six vertices, with 4 faces at each vertex. If all edges have the same length, it is one of the five regular polyhedra (Platonic Solids)*." [26] (SpringerLink 2001)

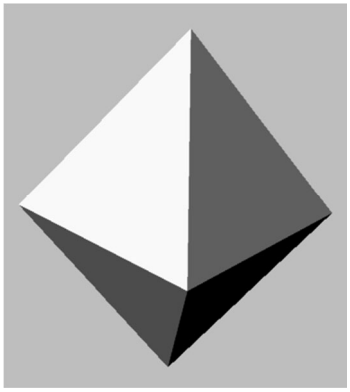


Figure 40: Octahedron in Rhinoceros.

The only one experiment of creating octahedron in Revit was unsuccessful in spite of its successful beginning. The experiment lasted about **an hour** and **half** with **1640** clicks.

[26] Encyclopedia of Mathematics, "Octahedron," SpringerLink, 2001, http://eom.springer.de/O/o068100.htm

Octahedron can be created by joining two identical pyramids. At the first 40 minutes of the experiment, the researcher was able to create a pyramid. The pyramid was created by joining four quarter pyramids. Void forms were part of the creation process. The problem started when the two pyramids were joined. The void forms showed up and made the geometry has illogic look as shown in Figure 41.

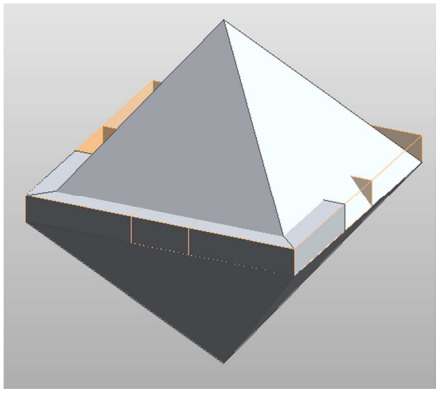


Figure 41: The final result of Octahedron geometry in Revit.

3.6.1.4.c. Complex Solids in Revit Architecture

3.6.1.4.c.i. Icosahedron

Sphere as defined mathematically in SpringerLink mathematical encyclopedia is: "*one of the five regular polytopes. An icosahedron has 20 (triangular) faces, 30 edges and 12 vertices (at each of which 5 edges meet). The regular polytopes are also called the Platonic solids.*"[27] (SpringerLink 2001)

[27] Encyclopedia of Mathematics, “Icosahedron,” SpringerLink, 2001, http://eom.springer.de/I/i050020.htm

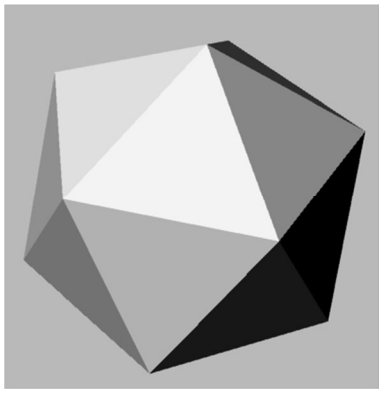


Figure 42: Icosahedron in Rhinoceros.

The experiment of creating Icosahedron in Revit has the same problems of creating Octahedron geometry. The experiment was failed and lasted about an hour. Icosahedron can be created by joining two pyramids with anti-prism as seen in Figure 43. The researcher was able to create the pyramids and the anti-prism, but the joining process was not successful because of the appearance of void forms.

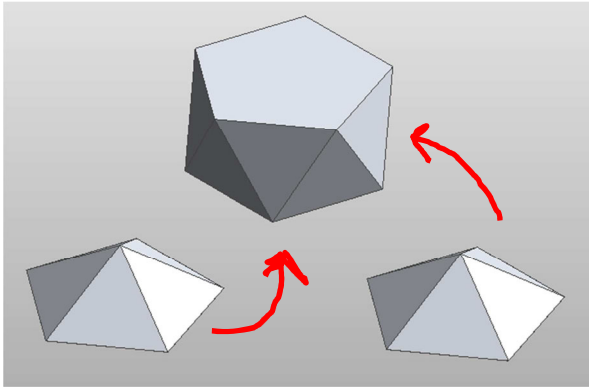


Figure 43: The geometries (pyramid and anti-prism) that Icosahedron is consisted of.

3.6.1.5. The Experiments of Surface geometries in Revit Architecture

This section illustrates some examples of surface geometries experiments in Revit Architecture. It cannot contain the explanation of all the experiments. Therefore, Appendix B in page 173 includes all the information about them.

3.6.1.5.a. Preliminary Surfaces in Revit Architecture

3.6.1.5.a.i. One Sheet Hyperboloid

Wolfram MathWorld defined hyperboloid mathematically as: "*a quadratic surface which may be one or two-sheeted. The one-sheeted hyperboloid is a surface of revolution obtained by rotating a hyperbola about the perpendicular bisector to the line between the foci, while the two-sheeted hyperboloid is a surface of revolution obtained by rotating a hyperbola about the line joining the foci.*"[28] (Weisstein 2011)

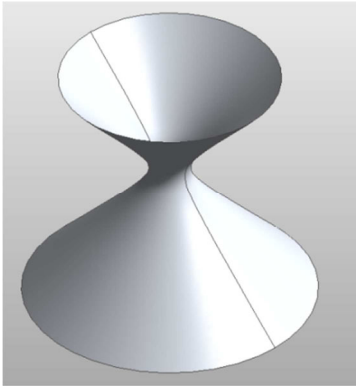


Figure 44: Hyperboloid one sheet in Revit Architecture.

[28] Eric Weisstein, "Hyperboloid," Wolfram MathWorld, 2011, http://mathworld.wolfram.com/Hyperboloid.html

Hyperboloid was created twice. The first experiment was not created according to the mathematical rules. Therefore, the resulted shape cannot be considered a hyperboloid. The second experiment was more accurate and based on the mathematical equation of hyperbola curve. The experiment was done in MMF and was successful (Figure 44). It took **forty three minutes** and **forty seconds** to draw the hyperbola curve, and about **fifteen minutes** to create the one sheet hyperboloid geometry with more than **2400** clicks. Figure 45 shows the options that Revit Architecture provided to create the hyperboloid.

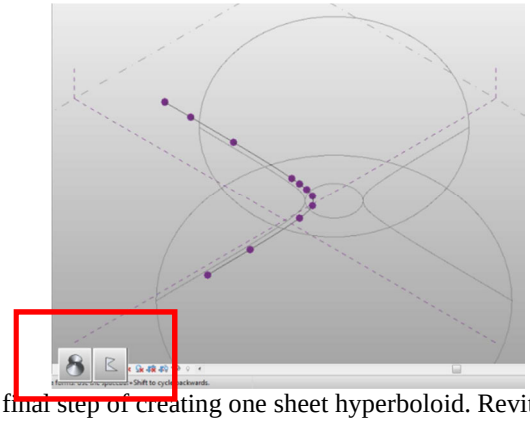


Figure 45: The final step of creating one sheet hyperboloid. Revit offers two options when using Create Form command, one of these options is the hyperboloid.

3.6.1.5.b. Secondary Surfaces in Revit Architecture

3.6.1.5.b.i. Elliptic Paraboloid

The elliptic paraboloid is*:" shaped like an oval cup and can have a maximum or minimum point. It is a paraboloid of revolution: a surface obtained by revolving a parabola around its axis*."[29] (Wikipedia 2011).

[29] "Paraboloid," Wikipedia, March 13, 2011, http://en.wikipedia.org/wiki/Elliptic_Paraboloid#cite_ref-0

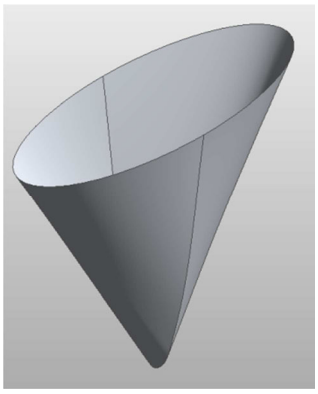


Figure 46: Elliptic Paraboloid in Revit Architecture.

The experiment of creating elliptic paraboloid was successful from its beginning (Figure 46). The researcher created it once and spent **ten minutes** and **twenty nine seconds** to create the parabola curve mathematically with **eighteen** steps. To create the elliptic paraboloid geometry, the experiment took an additional **thirteen minutes** and **twenty eight seconds** and an extra **twenty** steps. One of difficulties that the researcher faced during the experiment was the only option that Revit provide to draw the ellipse shape. Ellipse can only be created in Revit by specifying its center as illustrated in Figure 47. In other softwares, ellipse has more different options to draw, such as specifying its diameter, its corners, etc. These options are important sometimes in creation process.

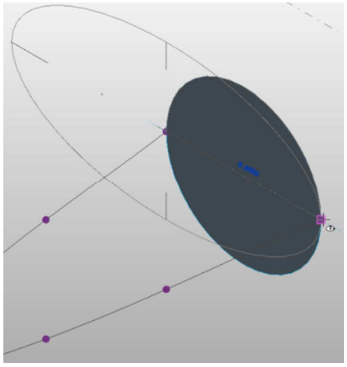


Figure 47: Drawing an ellipse in Revit.

3.6.1.5.c. Complex Surfaces in Revit Architecture

3.6.1.5.c.i. Mobius Strip

The definition of Wolfram MathWorld of the mobius strip is: "*a twisted cylinder (Henle 1994, p. 110), is a one-sided non orientable surface obtained by cutting a closed band into a single strip, giving one of the two ends thus produced a half twist, and then reattaching the two ends*."[30] (Weisstein 2011).

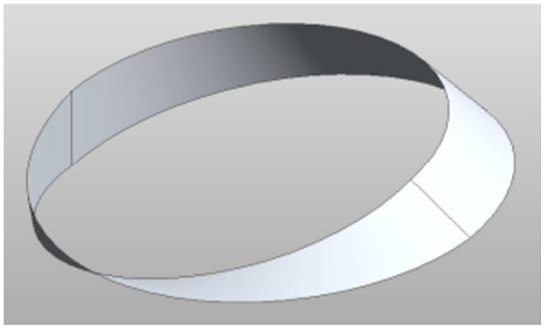


Figure 48: Mobius strip in Revit Architecture.

Mobius strip was created twice in Revit (Figure 48). The first experiment was not recorded. Therefore, the researcher tried to create it again. The experiment was done in **twenty one minutes** and **fourteen seconds**. The researcher created the geometry in **thirty three** step and **1629** clicks.

[30] Eric Weisstein, "Mobius Strip," Wolfram MathWorld, 2011, http://mathworld.wolfram.com/MoebiusStrip.html

3.6.1.6. Geometry Configuration and Transformation Stage and Final Form Recognizability stage in Revit Architecture

This section illustrates an experiment that simulates the process of GCT stage and FFR stage in Revit Architecture. As defined in the introduction chapter[31], Geometry Configuration and Transformation (GCT) is the second stage of GGDA. In this stage, the created geometry from IGP stage is developed. A number of operations such as Boolean, editing, NURBS, and other kinds of CAD operations, are applied on these geometries to create the final mass form of the design concept. On the other hand, FFR stage is the third and final stage of GGDA. In this stage, the final mass that is generated in the second stage of GGDA is transformed to a real building by applying Revit architecture's components on it such as walls, doors, curtain walls, etc.

Time, steps and clicks are also counted in this experiment, and the same softwares are used for time counting and steps recording. The results of the experiment are also documented and attached to the appendices of the thesis.

3.6.1.6.a. The finalizing of a Mass Form in Revit Architecture

The experiment of creating a concept mass in Revit Architecture as a simulation process of GCT stage was successful as shown in Figure 50, and lasted about **nineteen** minutes with **1104** clicks. In that experiment, a number of preliminary solids were chosen to create the mass form. These solids include: prism, cube and pyramid (Figure 49). The

[31] see page 4.

geometries were combined using Join command in Geometry panel in Modify tab. This command is similar in function to one of Boolean operations which is the union.

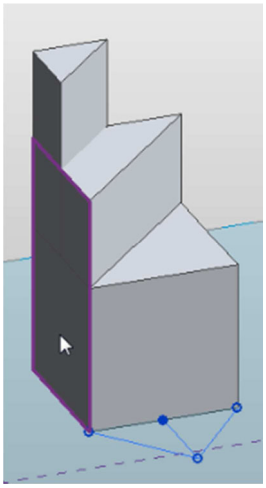


Figure 49: Adding a half of a pyramid to the form.

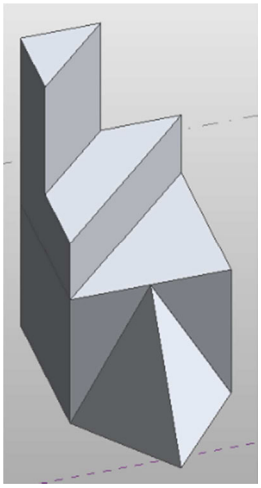


Figure 50: The final mass concept.

3.6.1.6.b. From a Mass form to a real building in Revit Architecture

The experiment of transforming the concept mass in Revit Architecture to a real building is a simulation process of FFR stage (Figure 52). This experiment was successful and fast. The operation of loading the mass from MMF to PF lasted no more than ***thirty*** seconds with ***nine*** steps and ***seventeen*** clicks. Once the mass is exported to PF as seen in Figure 51, the components such as walls, windows, floors, etc. can be applied easily and quickly on it. This experiment was the best experiment in Revit Architecture pursuant to time, steps, clicks and the ease of the operation.

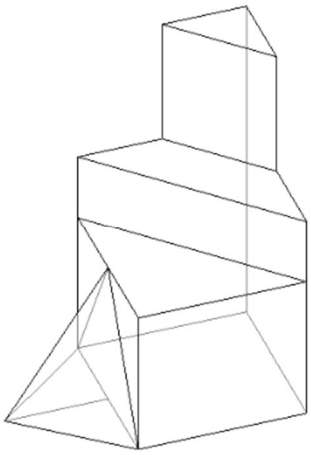


Figure 51: The loaded mass from MMF in PF.

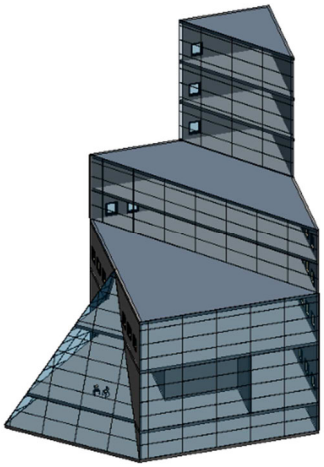


Figure 52: Mass is transformed to a real building in Revit Architecture

3.6.2. Rhinoceros 4.0

3.6.2.1. Initial Geometry Preparation Stage in Rhinoceros

Rhinoceros is one of the two design softwares in the comparative tools that are chosen to compare its abilities with Revit Architecture in working on GGDA. The experiments of examining Rhinoceros in IGP stage were similar to the experiments that examined Revit Architecture and ArchiCAD. They have the same variables, recording softwares and geometries.

3.6.2.2. About Rhinoceros

Rhinoceros software was first released in 1992 (McNeel Wiki 2011) by McNeel Company. It is considered one of NURBS Modeling softwares. It is able to create any geometry for any purpose. Therefore, it has been used in several design areas; it is used in product design, marine design, car design, architecture design, and jewelry design. Rhino has the ability to deform solids, surfaces, and meshes, the ability to draft and illustrate, the ability to render, and the ability to prototype (Rhinoceros 2010).

3.6.2.3. Solid Experiments in Rhinoceros

A number of solid geometry experiments are demonstrated in this section. The selected examples explain the method that all other experiments have followed. Appendix B in page 173 includes all information about these experiments.

3.6.2.3.a. Preliminary Solids

Rhinoceros software provides most of the preliminary solids that are listed in the methodology chapter. Therefore, most of the experiments of creating these geometries in Rhinoceros have been done in a shorter time than Revit Architecture. The default preliminary solids that Rhinoceros provides are: cube, sphere, ellipsoid, cone, pyramid, cylinder, tetrahedron, and Torus (Figure 53). Prism is the only preliminary solid in the list on page 41 that is not a default object in Rhinoceros. Thus, its creation will be explained in this section.

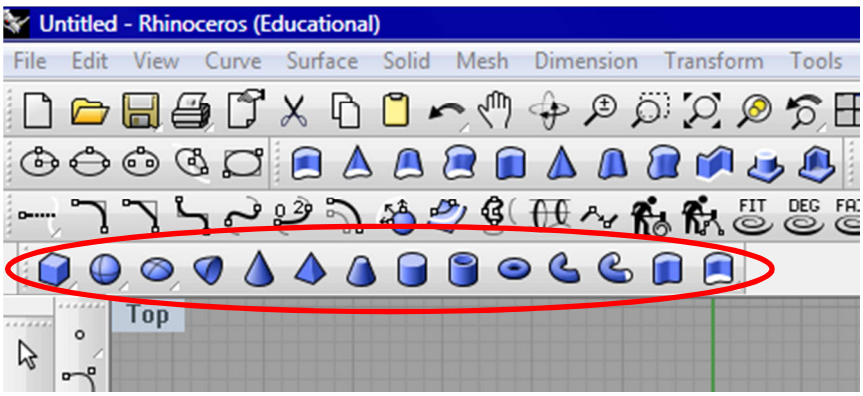


Figure 53: Default preliminary solids in Rhinoceros.

3.6.2.3.a.i. The Creation of Default Preliminary Geometries in Rhinoceros

The time that was spent in the experiments of creating each default preliminary solid in Rhinoceros did not exceed more than **two minutes** as maximum. Most of these experiments have the same steps, but they differ only in the parameters that characterize each geometry. For example, the creation process of sphere geometry in Rhinoceros needs to determine the center of the sphere and its radius, whereas the creation process of cone geometry in Rhinoceros needs to specify the center of the cone's base, diameter, and its height. Figure 54 illustrates the sphere and the cone geometries in Rhinoceros.

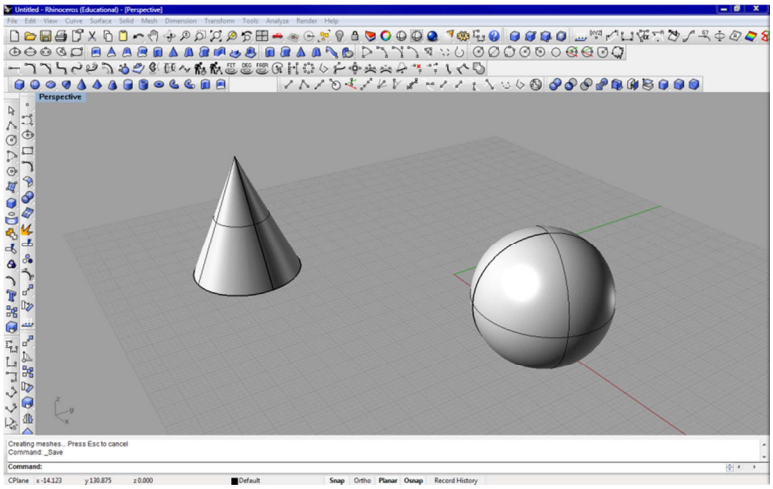


Figure 54: Sphere and cone in Rhinoceros.

On other hand, Rhinoceros offers different options to create each geometry. For instance, Rhinoceros provides seven options to create a sphere as shown in Figure 55; it can be created by determining its center and radius, by selecting three points, by determining its diameter, etc. These options give the user more freedom in the creation process to enable her/his design strategy.

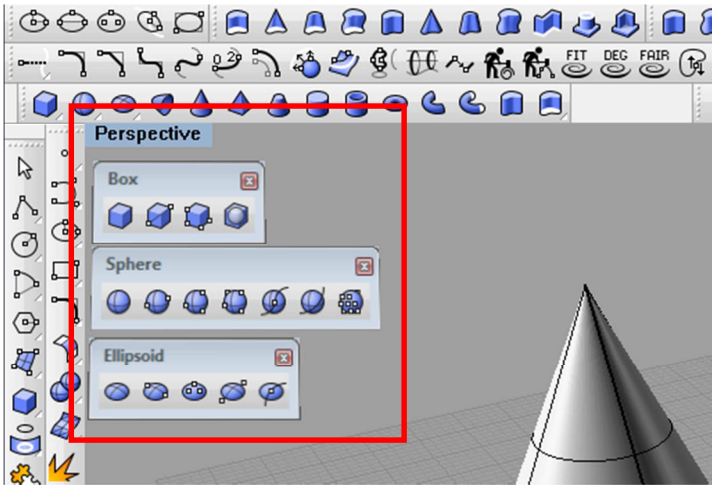


Figure 55: Creation options provided by Rhinoceros for Cube, Sphere, and Ellipsoid.

a. Sphere in Rhinoceros

The experiment of creating the sphere in Rhinoceros has similar steps of creating other default preliminary solids. This experiment was done successfully in **forty three seconds** and no more than **seven** steps and **twenty three** clicks.

Other default preliminary solids in Rhinoceros are created with the same method of sphere creation. The following figures in Table 5 show the generated geometries of these experiments and the time that was spent to achieve them.

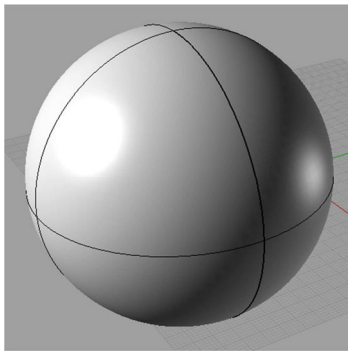
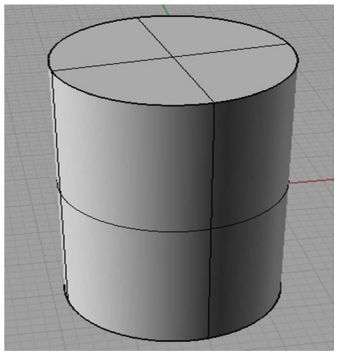
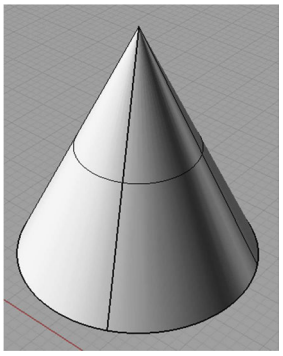
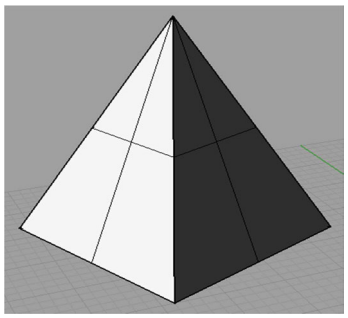
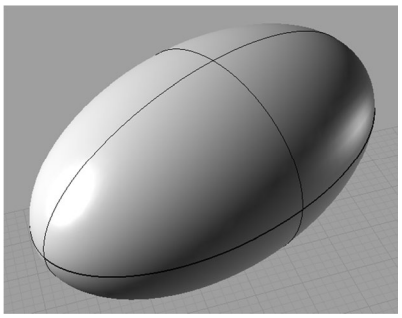
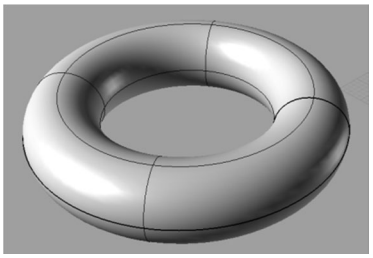
		
Sphere 00:00:13	Cylinder 00:00:10	Cone 00:00:07
		
Pyramid 00:00:10	Ellipsoid 00:00:07	Torus 00:00:07

Table 5: Shows preliminary solids that are default in Rhinoceros, and the time was spent

3.6.2.3.a.ii. The Creation of Non-Default Preliminary Solids in Rhinoceros (Tetrahedron)

The experiment of creating tetrahedron in Rhinoceros is similar to the previous experiments of default preliminary solids. However, the tetrahedron needs some calculations before starting the creation process. Therefore, the users have first to know the mathematical definition of the tetrahedron. Wolfram MathWorld defined tetrahedron geometry as: "*a polyhedron with four sides...The regular tetrahedron, often simply called "the" tetrahedron, is the Platonic solid with four polyhedron vertices, six polyhedron*

edges, and four equivalent equilateral triangular faces..."[32] According to this definition, the tetrahedron consists of four equilateral triangulars. The edges of the tetrahedron should have the same length, and the triangulars should have three equal 60^{o} angles (Figure 56).

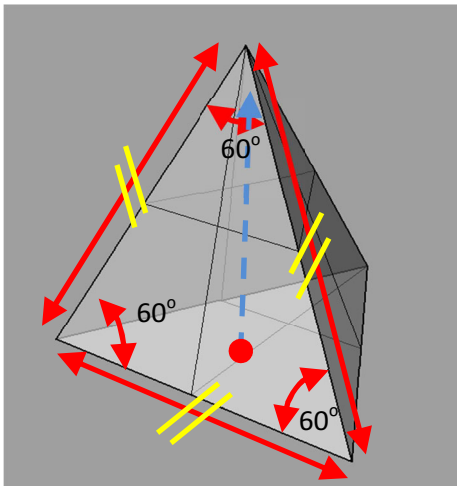


Figure 56: The mathematical rules of tetrahedron.

The tetrahedron was created twice successfully in Rhinoceros, with two different methods (Figure 57). In the first trial, the researcher did not know that the default pyramid option can help to create the tetrahedron geometry. Therefore, the tetrahedron was created by using the basic shapes such as lines, surfaces, etc. and took about **seven minutes** to be finished. While in the second experiment, the tetrahedron was created by using default pyramid geometry. This method lasted about **two minutes** and **twenty two seconds** with **nineteen** steps and **135** clicks.

[32] Frank Jackson and Eric W. Weisstein. "Regular Tetrahedron." Wolfram MathWorld, 2011, http://mathworld.wolfram.com/RegularTetrahedron.html

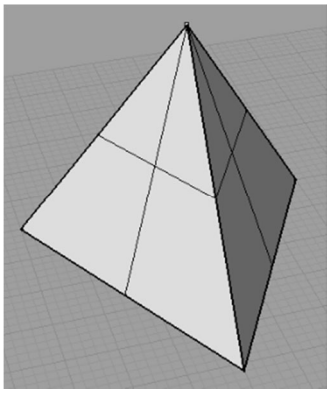


Figure 57: Tetrahedron in Rhinoceros.

3.6.2.3.b. Secondary Solids in Rhinoceros

3.6.2.3.b.i. Dodecahedron

SpringerLink mathematical online encyclopedia defined Dodecahedron as: "*one of the five types of regular polyhedra. A dodecahedron has 12 (pentagonal) faces, 30 edges and 20 vertices (with three edges meeting at each vertex).*"[33] (SpringerLink 2001)

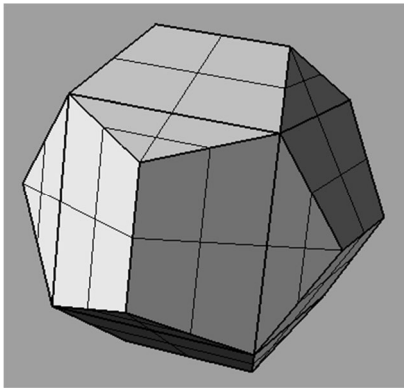


Figure 58: Dodecahedron in Rhinoceros.

[33] Encyclopedia of Mathematics, "Dodecahedron," SpringerLink, 2001, http://eom.springer.de/D/d033750.htm

Dodecahedron was created once in Rhinoceros as shown in Figure 58. It was created by joining a cube with six identical modified triangular prisms (Figure 59). The experiment took more than **fourteen minutes** with **fifty one** steps and **727** clicks.

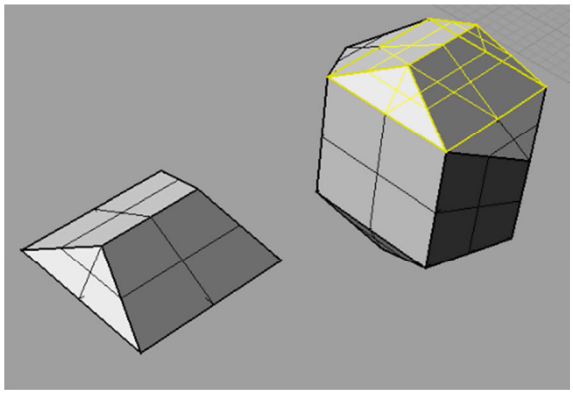


Figure 59: Creating dodecahedron by joining a cube with six identical triangular prisms.

3.6.2.4. The Experiments of Surface Geometries in Rhinoceros

This section reviews two examples of surface geometries experiments in Rhinoceros. The full details of other experiments can be found in Appendix B in page 173.

3.6.2.4.a. Preliminary Surfaces in Rhinoceros

3.6.2.4.a.i. Paraboloid

Wolfram MathWorld defined Paraboloid mathematically as: "*the surface of revolution of the parabola... It is a quadratic surface which can be specified by the Cartesian equation*

$z = b\,(x^2 + y^2)$."(Weisstein 2011)[34]

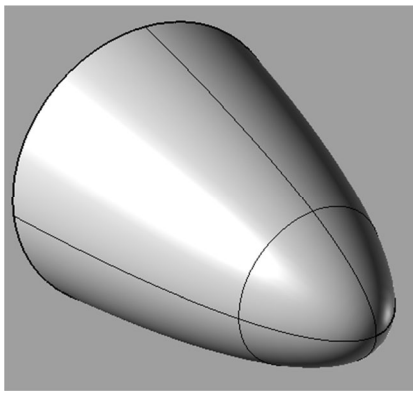


Figure 60: Paraboloid in Rhinoceros.

The paraboloid surface was created once in Rhinoceros. The experiment was successful and lasted only **twelve seconds** as seen in Figure 60. The default Parabola curve option in Rhinoceros was the reason for achieving the experiment with that short time (Figure 61). The creation process also was done using **seven** steps and **twenty two** clicks.

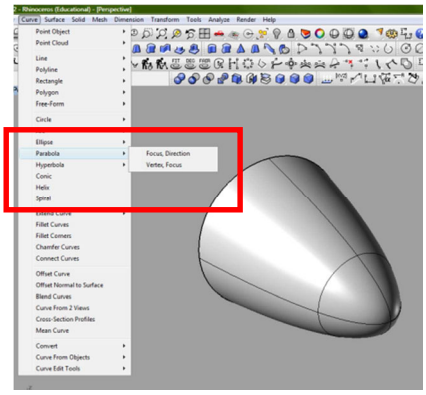


Figure 61: Default parabola curve in Rhinoceros.

[34] Eric Weisstein "Paraboloid." Wolfram MathWorld, 2011, http://mathworld.wolfram.com/Paraboloid.html

3.6.2.4.b. Secondary Surfaces in Rhinoceros

3.6.2.4.b.i. Hyperbolic Cylinder

The hyperbolic cylinder as defined mathematically in SpringerLink mathematical online encyclopedia is: "*a straight cylindrical surface of the second order with a hyperbola as directrix ...*"[35] (SpringerLink 2001)

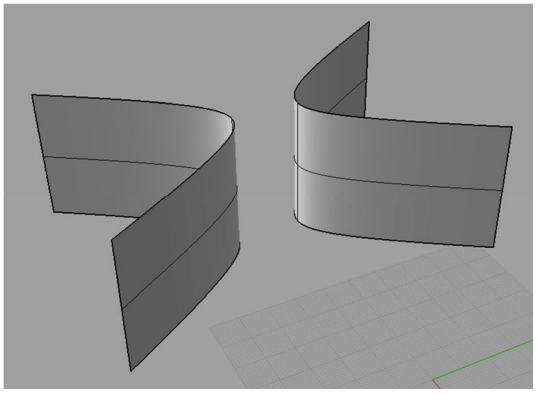


Figure 62: Hyperbolic Cylinder in Rhinoceros.

The experiment of creating hyperbolic cylinder in Rhinoceros was successful as illustrated in Figure 62. It lasted about **four minutes** with **85** clicks. In the first **three minutes** of the experiment, the researcher was able to create a hyperbola curve by using the default hyperbola curve option. Then, the curves were extruded using Extrude Closed Planar Curve command.

[35] Encyclopedia of Mathematics, "Hyperbolic Cylinder," SpringerLink, 2001, http://eom.springer.de/H/h048240.htm

3.6.2.5. Geometry Configuration and Transformation Stage and Final Form Recognizability Stage in Rhinoceros

This section introduces two experiments that were carried out in the main method to simulate the GCT and FFR stage in Rhinoceros. In these experiments, the IndVs and DepVs were considered, and time, steps and clicks were counted. The results of these experiments are documented and attached to the appendices of the thesis.

3.6.2.5.a. The Finalizing of a Mass Form in Rhinoceros

The experiment of creating a mass form in Rhinoceros is a simulation process of GCT stage. The geometries that were used are the same geometries that used in Revit Architecture. These geometries are preliminary geometers, and include: prism, cube and half of a pyramid as seen in Figure 63. The experiment was successful and lasted about ***eleven*** minutes with **677** clicks. The time of the experiment and the number of clicks were less than the time and clicks in Revit Architecture's experiment.

The geometers were united by using the Boolean Union operation that is available in the toolbars on the interface of Rhinoceros.

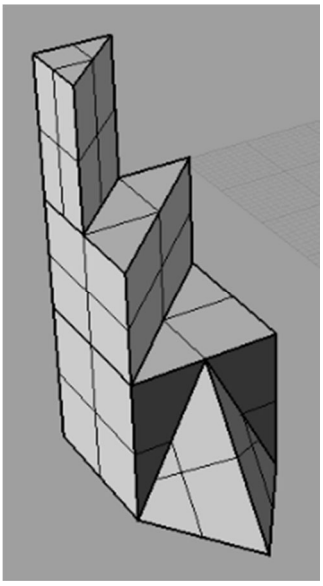


Figure 63: The final mass concept in Rhinoceros.

3.6.2.5.b. From a Mass Form to a Real Building in Rhinoceros

The process of transforming the mass in Rhinoceros to a real building has two options, because Rhinoceros has no default components that can be applied on the form. The first option is represented in creating the components individually on the mass directly. This process takes a long time to configure each component. The second option is exemplified by exporting the mass to Revit Architecture and applies the components in the PF file. The experiment that simulates FFR stage in Rhinoceros in this thesis followed the second option. The created mass in Rhinoceros was exported to the PF file in Revit Architecture successfully. This process lasted about ***four*** minutes with ***eighteen*** steps and ***120*** clicks. We can notice the obvious difference in the time and the number of steps and clicks of this process with the results of the same experiment in Revit Architecture[36]. The exported mass from Rhinoceros to PF was employed as a mass that was created in Revit

[36] See Appendix B.

Architecture (See Figure 64). The components were applied on the mass easily and smoothly. Figure 65 shows the results of FFR stage on the mass that was created in Revit Architecture and the mass that was created in Rhinoceros.

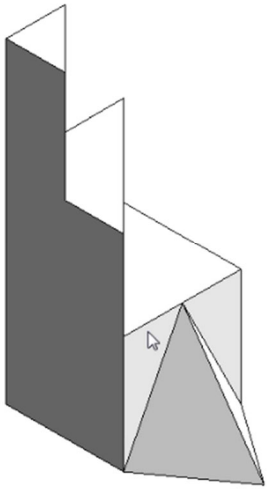


Figure 64: The loaded mass from Rhinoceros to PF file in Revit Architecture.

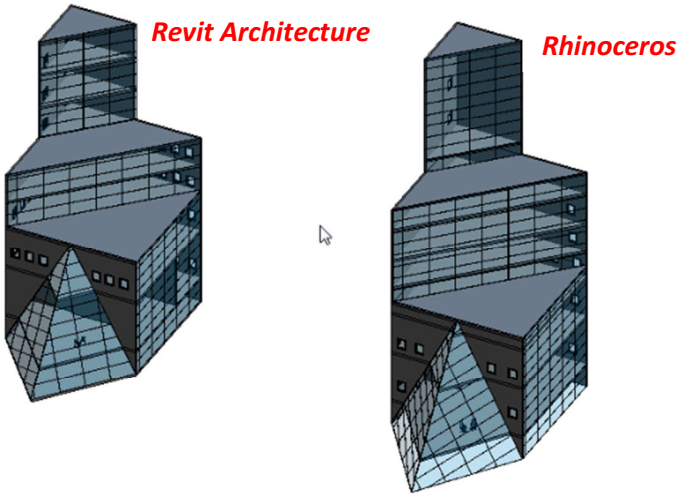


Figure 65: Comparing the results of FFR experiment between Revit Architecture and Rhinoceros.

3.6.3. ArchiCAD 14

3.6.3.1. Initial Geometry Preparation Stage in ArchiCAD

This section explains a number of the experiments in ArchiCAD that explored its abilities in the IGP stage. These experiments are similar to the previous experiments in Revit Architecture. The same procedures are followed; counting time, recording steps and clicks using the same softwares.

However, the created geometries in IGP stage are examined early in the FFR stage in ArchiCAD. This examination shows that ArchiCAD components as walls, doors, curtain walls, etc. cannot be applied to the created geometries. The software cannot transform them into real buildings. The geometries can only be used in ArchiCAD to create other components such as furniture, roofs, doors, and etcetera. As a conclusion, GGDA is not applicable in ArchiCAD because of the unfeasibility to work on FFR stage. Therefore, the researcher eliminates ArchiCAD as a comparative tool.

3.6.3.2. About ArchiCAD 14

ArchiCAD was established for the first time in 1984 (Goldberg 2005) by Graphisoft company. It is considered at present, one of the oldest and most important BIM applications. It is specialized like Revit in AEC industry. However, ArchiCAD does not have multiple products like Revit has. There is no special product or file for each discipline. All disciplines can work on the same version and all designs whether architectural or structural are created in the same type of file. For instance, geometries

and detailed drawings can be created in the same type of ArchiCAD file (.pln*) as shown in Figure 66.

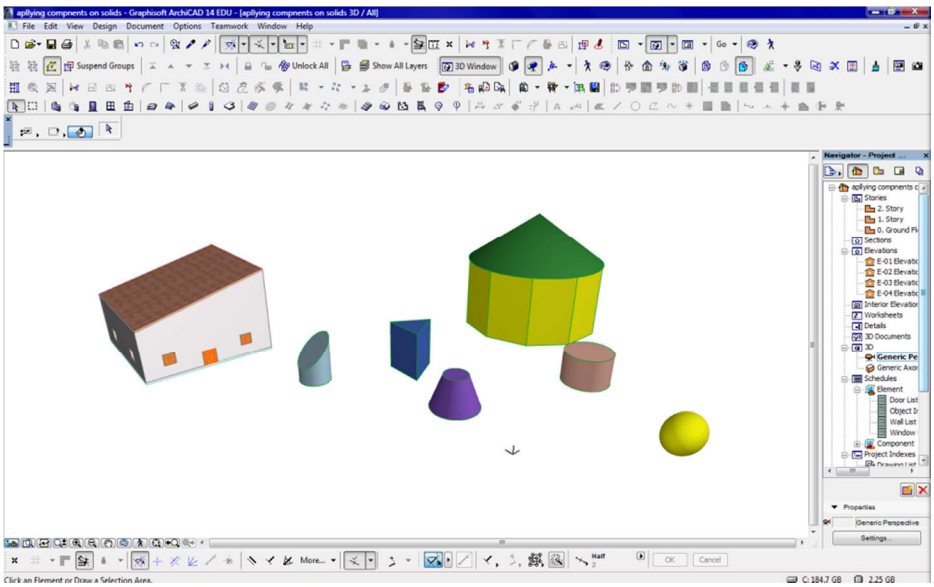


Figure 66: Mass modeling and detailed building in the same file in ArchiCAD.

3.6.3.3. The Experiments of Creating Geometries in ArchiCAD

This section illustrates some examples of solid and surface geometries experiments in ArchiCAD. The description of all experiments cannot be included. Appendix B in page 173 includes all the experiments in details.

3.6.3.3.a. Solids in ArchiCAD

Most of the preliminary and secondary solids that are listed in this thesis are available in the ArchiCAD library. This library provides the designer with most of these geometries and offers the ability to modify their parameters before adding them to an ArchiCAD file.

The default preliminary and secondary solids that are available in ArchiCAD are: cube, cone, cylinder, sphere, prism, pyramid, ellipsoid, truncated cone, oblique circular cone, right circular cone, and oblique circular cylinder. The following section provides examples of the experiments.

3.6.3.3.a.i. The Creation of Sphere in ArchiCAD

The process of creating the sphere in ArchiCAD is similar to the process of creating other default solids. The difference lies in the number of parameters that characterize each solid within Object Default Setting. The sphere for example has two parameters: center and radius, whereas the pyramid has six parameters.

The sphere in ArchiCAD was created once as seen Figure 67. The experiment lasted **two minutes** and **nineteen seconds** with about **seven** steps.

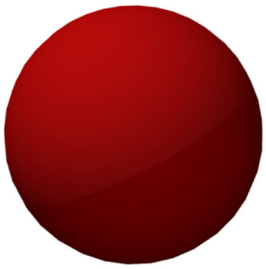


Figure 67: Sphere in 3D view in ArchiCAD.

The previous steps in creating the sphere in ArchiCAD are the same steps to create other default preliminary solids. Table 6 illustrates the final results of these solids.

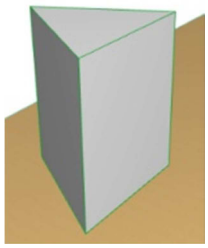
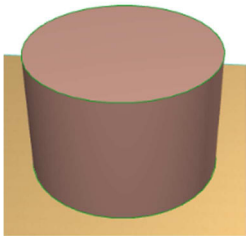
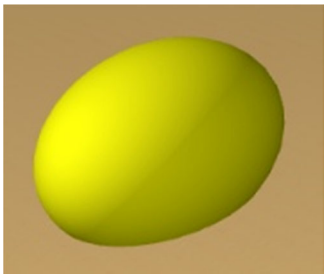
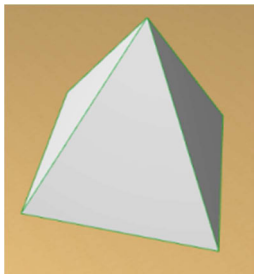
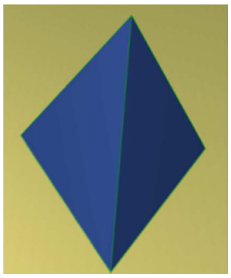
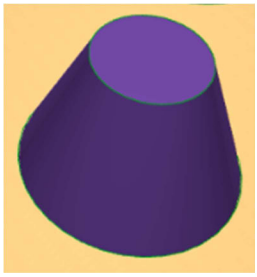
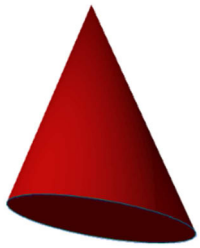
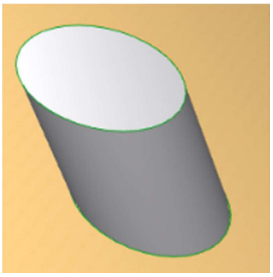
		
Prism	Cylinder	Cone
		
Ellipsoid	Pyramid	Tetrahedron
		
Truncated Cone	Oblique Circular Cone	Oblique Circular Cylinder

Table 6: preliminary and secondary solids that are default objects in ArchiCAD.

Due to the early conclusion about the unfeasibility of ArchiCAD to work with GGDA, the number of clicks of the previous experiments were not counted and included in the Appendix B. Furthermore, the experiments of creating other geometries were cancelled and removed from the comparison process between Revit, Rhino, and ArchiCAD.

3.6.3.4. The Generative Design Approach of ArchiCAD

According to the previous experiments in ArchiCAD, GGDA is not the suitable approach to work on it. This conclusion is a result of examining the previous geometries in the FFR stage. In these experiments the researcher tried to apply components such as walls, doors, etc. on the faces of the geometries. These trials were unsuccessful as shown in Figure 68 and proved that geometries in ArchiCAD can only be used to create other components such as furniture, windows, etc.

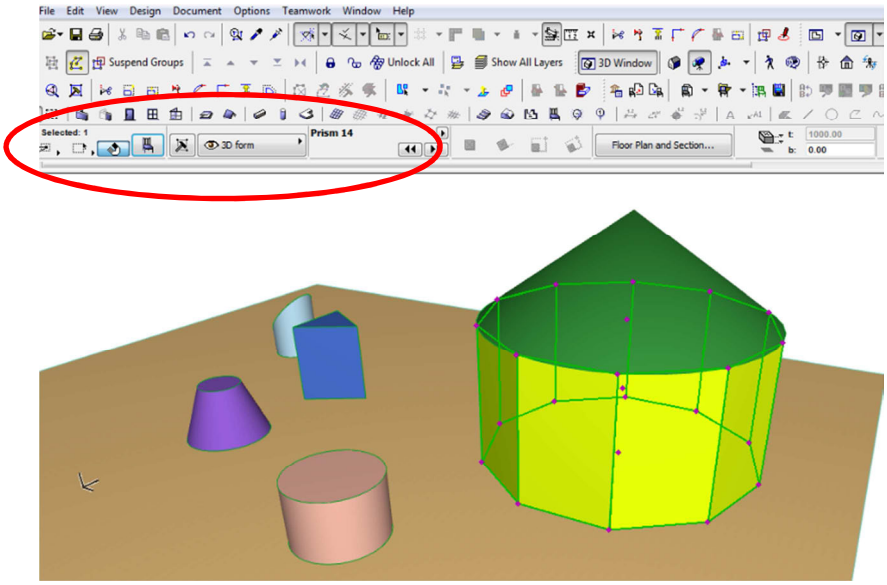


Figure 68: The experiment of applying the FFR stage on geometries in ArchiCAD.

As a result of several experiments of finding the suitable generative design approach for ArchiCAD, it was found that a designer who uses ArchiCAD has to build their design concepts directly using BIM components. The conceptual design phase was abandoned in the software. The designers have to plan for their design concepts before starting work on ArchiCAD. They can prepare these concepts in manual sketches, using design software,

or using the default geometries in the ArchiCAD library. The manual sketches and the masses that are created in other softwares have to be translated again with the components of ArchiCAD. Graphisoft Company provides training videos that show the way to create conceptual masses in ArchiCAD as seen in Figure 73, but it doesn't explain the possibility to develop these masses to real buildings. Figure 69, Figure 70, Figure 71, and Figure 72 show the results of creating some surfaces by using ArchiCAD components.

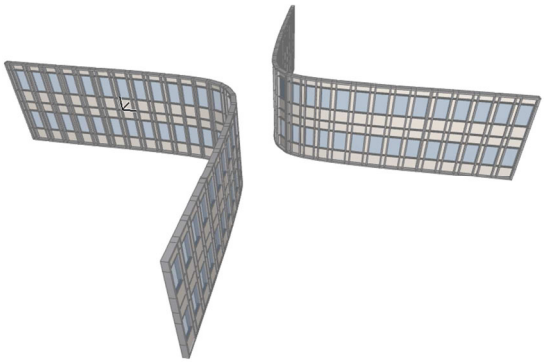


Figure 69: Curtain Wall with Hyperbolic Cylinder geometry.

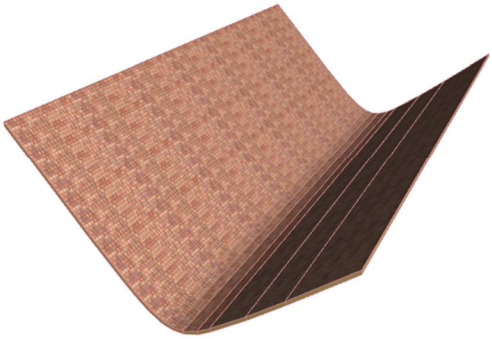


Figure 70: Roof with Parabolic Cylinder geometry.

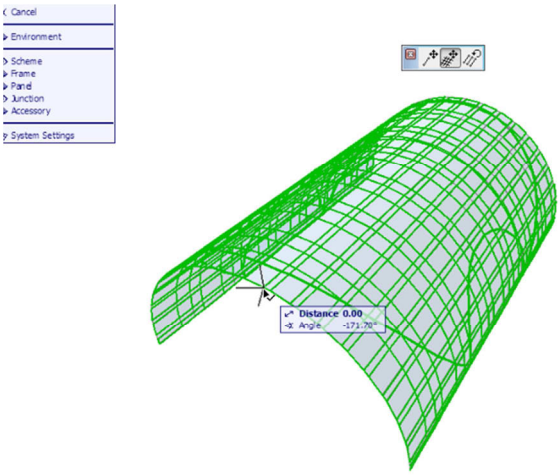


Figure 71: Creating complex geometry curtain wall.

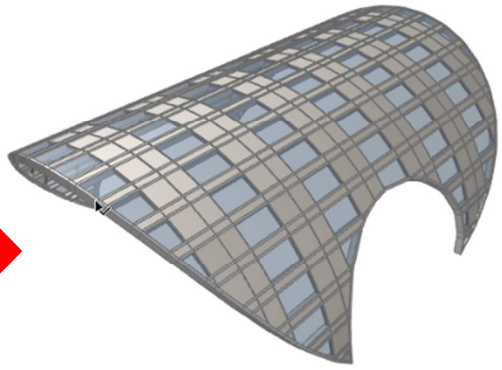


Figure 72: Complex shape of curtain wall.

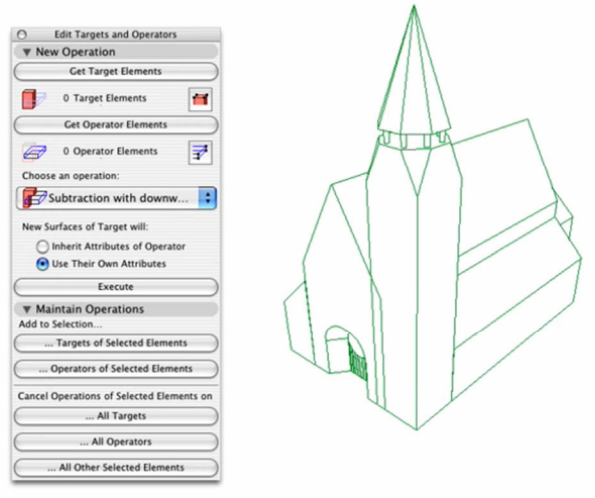


Figure 73: Graphisoft video shows how to create conceptual mass in ArchiCAD (Graphisoft).

3.7. Confirmation Method

In the confirmation method, five students in the college of Architecture in UNL worked on two experiments. These experiments have the same procedures, variables, and tools of the main method's experiments. This method explores the possible effects of the user, computer's capabilities and the surrounding environment on the abilities of Revit Architecture in creating the geometries on page 41. The goal of the confirmation method is to confirm the validity of the main method's results, and to avoid any possible bias in them to strengthen the internal validity[37] of the research.

3.7.1. The Hypothesis of the Confirmation Method

The hypothesis of the confirmation method is concerned only on the first stage of GGDA (IGP), because the experiment of this method examined only this stage. The hypothesis is presented in the following table:

Hypothesis	Result
Autodesk Revit Architecture is able to create: • Preliminary solids. • Preliminary surfaces. • Secondary solids. • Secondary surfaces. • Complex solids. • Complex surfaces.	Autodesk Revit Architecture has the ability to work on ***Initial Geometry Preparation stage*** in GGDA.

[37] **Internal Validity** is*" the approximate truth about inferences regarding cause-effect or causal relationships. Thus, internal validity is only relevant in studies that try to establish a causal relationship*." (Social Research Methods 2006, Internal Validity)

It was difficult for the researcher to examine all the stages of GGDA in the confirmation method due to the constraints of the experiment's time. The time of the experiment was limited only in two hours and a half, this limitation is a result of the coming reasons:

- The researcher determined the time of the experiment to three hours maximum to encourage the students to volunteer for the experiment. If the time of the experiment was more than three hours, the students will avoid the participation because of their preoccupation with their studies and classes.
- The difficulties that the researcher faced to find a computer lab to carry out the experiment.
- The experiment was carried out in a computer lab that has busy time schedule. The lab was reserved most of the days of the week which was difficult for the researcher to find an enough open suitable time for the experiment which also suits the time schedules of all participants.
- The experiment was operated in a very belated time in the schedule of the research. It was carried out a month before the deadline of the final submission of the research. This lateness is due to some administrative obstacles that the researcher faced: the delay of obtaining the approval from the Institutional Review Board (IRB) to work on the experiment, the delay of acquiring a permission to use the computer lab, the long process of coordinating between the suitable time for the participants and the open time of the lab, and the slow process of installing the softwares of the experiment to the computers of the lab.

These reasons also are prevented the researcher to examine the other stages of GGDA, and to work on additional confirmatory experiments.

Obtaining an approval from the Institutional Review Board (IRB) before working on the confirmation method was necessary. The routing process of IRB lasted more than a month, and was approved on the 15th of February 2011. The process included an online Collaborative Institutional Training Initiative (CITI) course, and a detailed form about the experiments and their goals. In the detailed form, the researcher submitted all the documents about the experiments: the questionnaires and the informed consent. These documents are attached in Appendix H on page 267.

3.7.2. Confirmation's Experiments

The participants of the experiment of the confirmation method are five male students in Arch 511, Arch 611 courses. They volunteered after they listened to oral announcements by the researcher in their classes. The researcher announced her need of volunteers to work on her thesis's experiment. She explained the overall objective of the experiment without in-depth details to avoid bias in the results. The announcement speech is included in Appendix H.2 on page 267.

On the 25th and 26th of February in 2011, the participants worked on two experiments. Each experiment took about half an hour of time, and was carried out in New Media Center (NMC) in the college of Architecture. Before the participants began to work on

the experiments, they were asked to read and approve their agreement on an informed consent paper[38]. They were also asked to fill out an online pre-questionnaire[39] created with a survey website. The pre-questionnaire includes questions that are derived from the independent variables[40] that might affect the results of the experiments. These questions are concerned about the personal demographic of the participant, and their previous experience in using Revit Architecture and Rhinoceros. They are also concerned about the attitude of the students and their psychological and physical states on the day of the experiment. Collecting this information about the participants is important for the analysis process, because it is considered the IndVs of the participants.

In the two experiments, the students created three geometries among the geometries that are listed on page 41. The three selected geometries for the confirmation method are: triangular prism, right circular cone, and mobius strip as shown in Table 7. The researcher chose these three geometries because the participant's should create geometries with different levels of complexity and these geometries should be a mixture of solid and surface categories; the prism is a preliminary solid, whereas mobius strip is complex surface.

[38] See Appendix H.1.
[39] See Appendix G.1.
[40] See page 44.

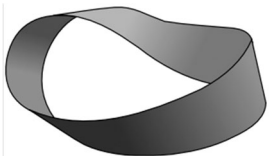
		
Triangular Prism	Right Circular Cone	Mobius Strip

Table 7: The three geometries that were created in the confirmation method's experiments.

The five students examined Rhinoceros in the first experiment to create the three geometries, whereas they examined Revit Architecture in the second experiment to create the same geometries. The decision of working on Rhinoceros in the first experiment is due to the inflexibility of Revit architecture which might lead the participants to get tired early and to feel bored immediately if they worked on Revit first. These feelings have a significant effect on the results of the experiments, and might drive the students to leave the experiment before completing the creation process.

An additional online questionnaire[41] was answered by the participants directly after completing their work on both experiments. This post-questionnaire helped the participants to evaluate their second experiment with Revit Architecture. They were asked about their satisfaction with the results of the experiment, their evaluation of the interface of Revit and other personal views about the software and the experiment. The entire process of the confirmation method lasted about an hour and a half.

[41] See Appendix G3.

The following table shows the hardware and softwares that are used in the confirmation method:

Hardware	Software	Hardware and software for Recording the process of Experiment
• Computer model: MacBook Pro 2009 ✓ • Processor: Intel (R) Core (TM)2 Duo T9550@ 2.66 GHz 2.66 GHz✓ • Display:1920X1200✓ • Memory: 4.00 GB ✓ • Disk Storage: 296 GB ✓ • System type: 64-bit Operating System • Window Edition: Windows 7 Interprise 2009✓ • Web Camera: ---------- • Video Card: NVIDIA Geforce 9600 M GT 8.15.11.8684✓ • Speakers & Microphone: Realtek High Definition Audio 6.0.1.5936 • Mouse driver: HID-compliant mouse. • Mouse brand: - Logitech - Microsoft 3-button with scroll wheel.✓	• Autodesk Revit Architecture 2011 x64 , 2010 ✓ • Rhinoceros 4.0 SR5b, 2009.	• Video Digital Camera • Speakers & Microphone: Realtek High Definition Audio 6.0.1.5936 • Camtasia Studio 2.0.0.47, 2010. • Mousetron 6.1

Table 8: Shows the used hardwares and softwares in confirmation method.

Chapter 4. Analysis Process

This chapter presents the data that were collected in the methodology. The methodology is composed of two sub-methods: main method, and confirmation method as shown in Diagram 8. In the main method, the researcher was the only participant in the simulation process of GGDA, whereas five students in the college of Architecture in UNL were the participants in the confirmation method.

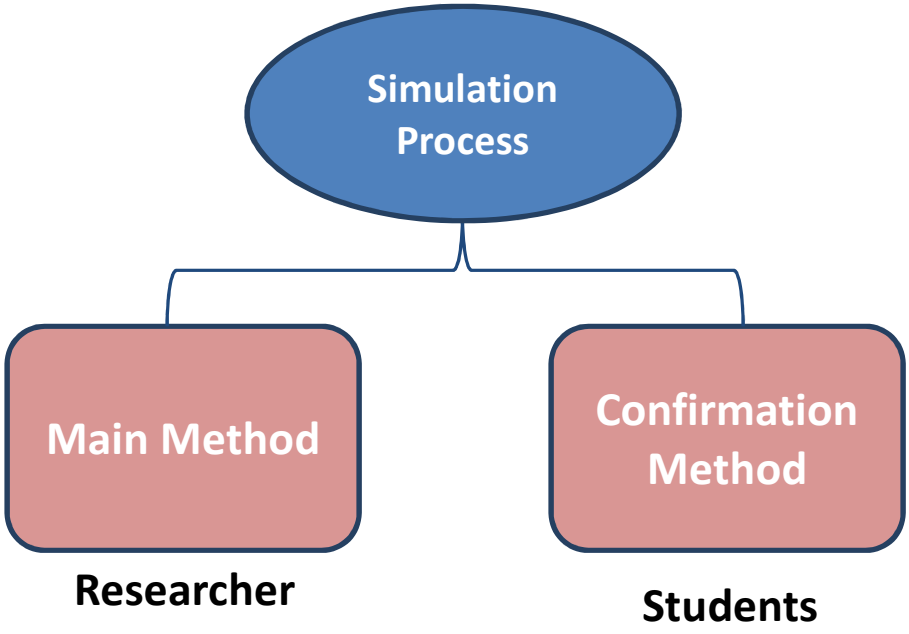


Diagram 8: The diagram shows the methods of the simulation process, and the participants of each method.

The analysis process of the collected data is the same for both methods. Independent variables on page 44 were considered significantly in the analysis process. These variables differ in each method and also differ for each participant. They have a great impact on the results. In the next sections, the analysis process of each method is

explained in detail, and the obtained data are available in the appendices at the end of this thesis.

4.1. Analysis Process of the Main method

In the main method, the researcher conducted 91 trials[42] of 50 experiments[43] of creating geometries. The process took five months to be ended; it started in September 19, 2010, and ended in February19, 2011.

Researcher's Experiments		Revit Architecture		Rhinoceros		Total Number of experiments
Geometry	Number of Geometries	Successful	Failed	Successful	Failed	
Preliminary solids	8	8	0	8	0	16
Secondary solids	9	7	2	9	0	18
Complex Solids	1	0	1	1	0	2
Preliminary Surfaces	3	3	0	3	0	6
Secondary Surfaces	3	3	0	3	0	6
Complex Surfaces	1	1	0	1	0	2
Total	25	22	3	25	0	50

Table 9: Shows the number of successful and failed experiments that were done by the researcher for each software

It is observed that Revit Architecture has succeeded in 88% of the experiments by creating 22 geometries of the total 25, whereas Rhinoceros achieved 100% of the geometries. A slight difference can be noticed in the results of the number of successful

[42] ***Trial*** is the attempt that the user tries to create the geometry in the experiment; and it could be successful or failed trial. See Diagram 5 on page 55.
[43] ***Experiment*** means the process of creating one geometry in one software. See Diagram 5 on page 55.

experiments, and the good achievement of Revit in creating the geometries. On other hand, the Table 9 illustrates different results in the comparison between the number of successful and failed trials:

Researcher's Trials	Revit Architecture		Rhinoceros		Total number of Trials
Geometry	Successful	Failed	Successful	Failed	
Preliminary solids	19	12	10	0	41
Secondary solids	15	7	10	0	32
Complex Solids	1	1	2	0	4
Preliminary Surfaces	3	0	3	0	6
Secondary Surfaces	3	0	3	0	6
Complex Surfaces	1	0	1	1	3
Total	42	20	29	1	91
Time spent	7:24:38	16:28:29	2:33:23	0:31:58	

Table 10: Shows the number of successful and failed trials that were done by the researcher for each experiment.

The Table 10 demonstrates the number of successful and failed trials that were conducted by the researcher. It is noticeable that the researcher worked on 62 trials in Revit to achieve 22 successful experiments (Table 9) in approximately 23 hours of time. However, she worked on only 30 trials in Rhino to achieve the 25 successful experiments (Table 9) in estimated three hours of time. It is also obvious that the researcher spent

about 16 hours working on 20 unsuccessful trials in Revit Architecture, whereas she worked on 42 successful trials in about seven hours. This means that ***for each failed trial*** in Revit Architecture, there are ***two successful trials*** with rate of ***50 minutes*** of wasted time to ***20 minutes*** of productive time in Revit Architecture.

In the case of Rhino, the researcher spent half an hour on one failed trial, while she worked on 29 successful trials in two hours and a half. Accordingly, ***for each failed trial*** in Rhino there are ***29 successful trials*** with rate of ***30 minutes*** of wasted time to ***150 minutes*** of productive time in Rhinoceros.

In Table 9, the results showed the significant achievement of Revit Architecture in creating 88% of the listed geometry. Whereas in Table 10, the results demonstrate the difference in the ratio between the wasted and productive time, and illustrate the considerable distinction in the ratio between the failed and successful trials.

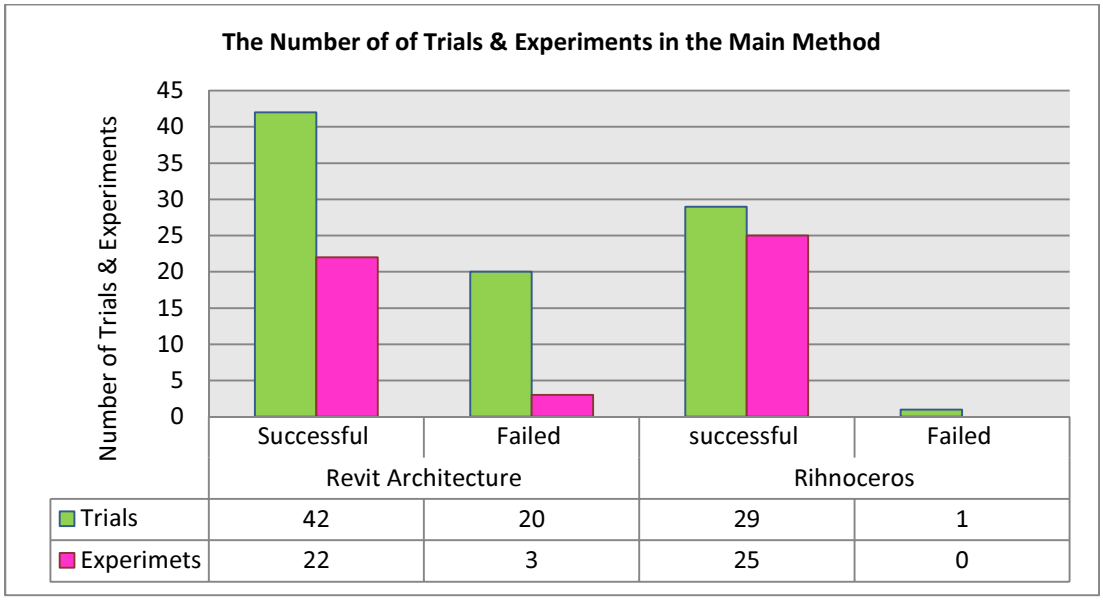


Chart 4: The number of successful & failed trials and experiments in Rhino and Revit Architecture.

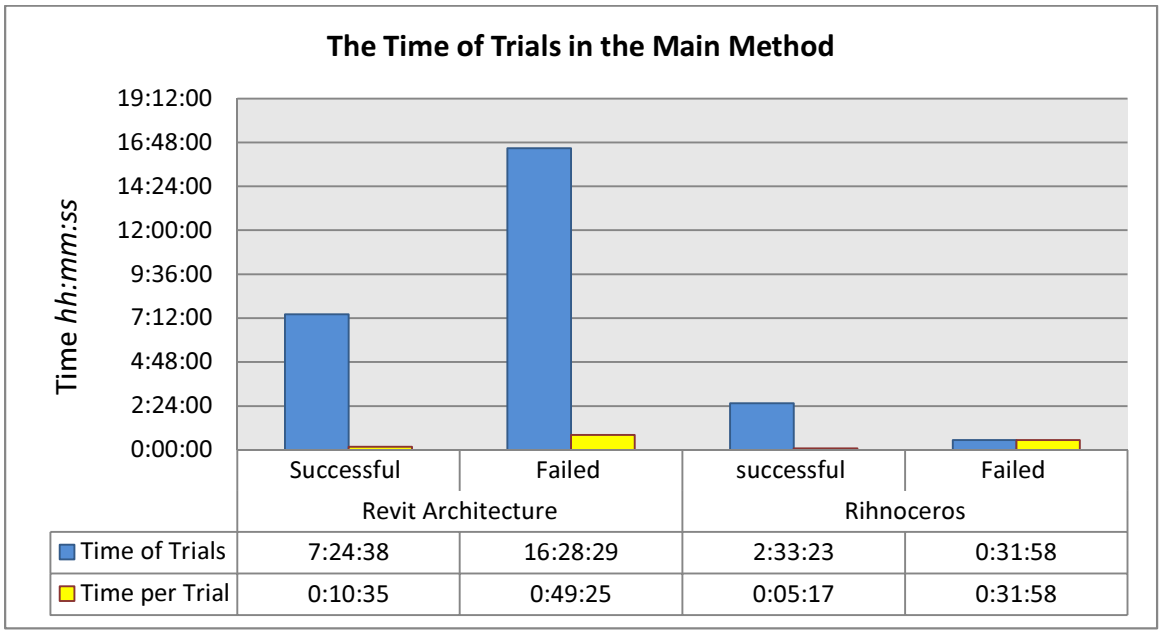


Chart 5: Shows the difference in the time of trials between Revit Architecture and Rhinoceros.

Therefore, the independent variables that are listed and explained in the methodology chapter on page 33 should be considered in the analysis process to identify the possible impacts of them on the results.

4.1.1. The Independent Variables in the Main Method

The independent variables (IndV) are important factors in the analysis process of the thesis's methodology. They are different from one participant to the other and from experiment to another experiment. For that reason, the researcher specified these variables in the methodology chapter before starting the analysis process. The independent variables for the main method are divided in the following table:

Constant IndV			**Changeable IndV**
Work place Environment	Good Environment		***Psychological & Physical Aspects***
Computer's Capabilities	Good Capabilities		
Software Interface	Rhino	Revit	
	Useful Interface	Moderate Interface	
User Attitude	Poor attitude	Poor Attitude	
Previous Experience	Not Enough	Not Enough	***User Expectations***
Previous Use in Architectural Design	Yes	Yes	

Table 11: demonstrates the IndVs in the main method.

With regard to the interface evaluation in the previous table, a comparison between the interfaces of Revit Architecture and Rhinoceros was done by the researcher[44]. This comparison is dependent on a criteria was accomplished by Han X. Lin, Yee-Yin Choong, and Gavriel Salvendy (Lin et al. 1997, 276-277) to compare the usability of different softwares. The comparison also was based on guidelines for interface comparing by Sidney L. Smith and Jane N. Mosier (Smith and Mosier). The comparison found that Revit's interface is superior with some factors on the interface of Rhinoceros. These factors include the consistency, memory load, perceptual limitations and other options. On other hand, Rhinoceros exceeds Revit with some other factors, for example the compability, the flexibility and other factors are shown in Table 12. According to this

[44] See Appendix D.

comparison, Rhinoceros proved that its interface has the most factors that make it better than the interface of Revit Architecture. This result was approved in the analysis process of both methods: main and confirmation methods. The next table shows the final results of the comparison.

Usability Evaluation Factor	Revit Architecture (MMF)	Rhinoceros
Compability	**2.5**[45]	**3**✓
CONSISTENCY	**20**✓	**17.5**
FLEXIBILITY	**8.5**	**9.5**✓
LEARNABILITY	**0.5**	**3**✓
MINIMAL ACTION	**5.5**	**6**✓
MINIMAL MEMORY LOAD	**5**✓	**5**✓
PERCEPTUAL LIMITATION	**4.5**✓	**4**
USER GUIDANCE	**3.5**	**5**✓
Other Options	**13.5**✓	**13**

Table 12: illustrates the results of the comparison between the interface of Revit and the interface of Rhinoceros.

The next diagrams illustrate the constant variables for the user in the main method. These constant variables cannot be changed in any of the experiments as long as it is the same user in all of them. They include *work place environment* and *computer's capabilities*. While *User Attitude*, *Previous Experience* and *Interface* are changeable variables according to the used software as well as the user.

[45] These number are the number of **Yes** answers in the table of the comparison in Appendix D on page 202.

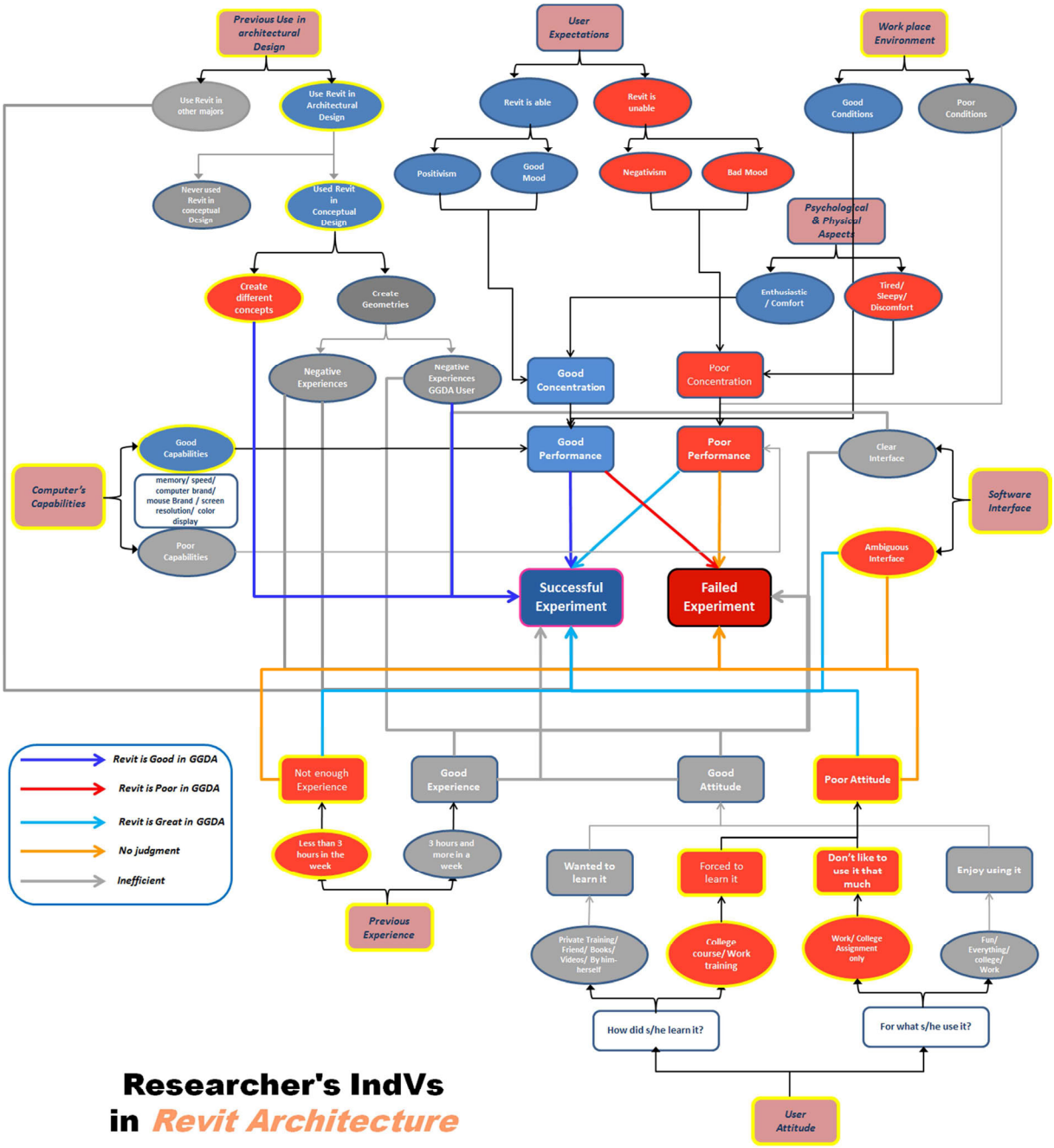


Diagram 9: Shows the correlation between the IndVs of the researcher in Revit Architecture.

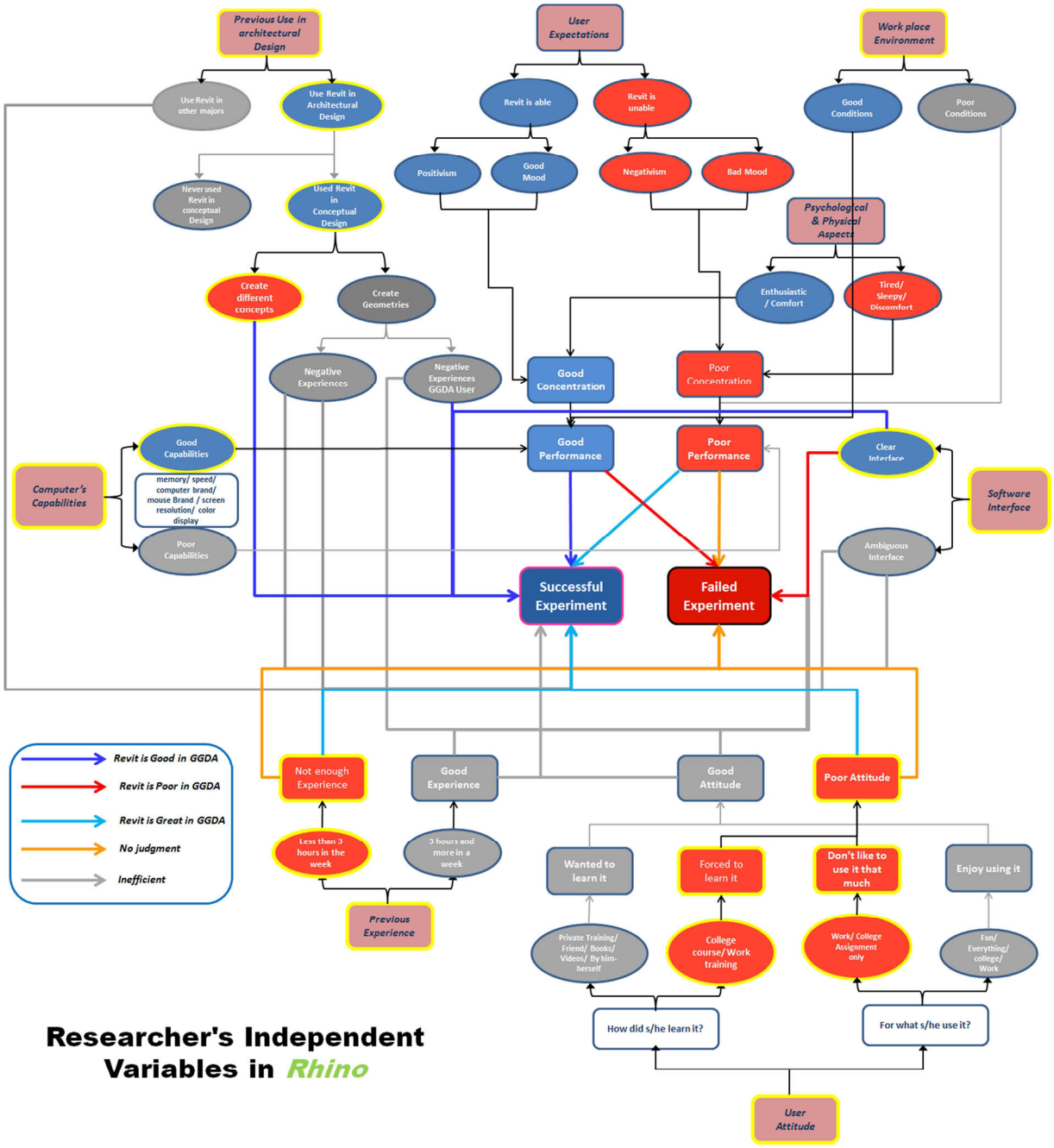


Diagram 10: Shows the correlation between the IndVs of the researcher in Rhinoceros.

4.1.2. Analysis Strategy of the Main Method

The collected data from the experiments are the DepVs that are listed in the methodology chapter[46]. These data were analyzed using the IndVs as shown in the Diagram 11[47]. The primary data are gathered and collected in a table in Appendix B. They include: Steps, Clicks, Time and difficulties for each experiment.

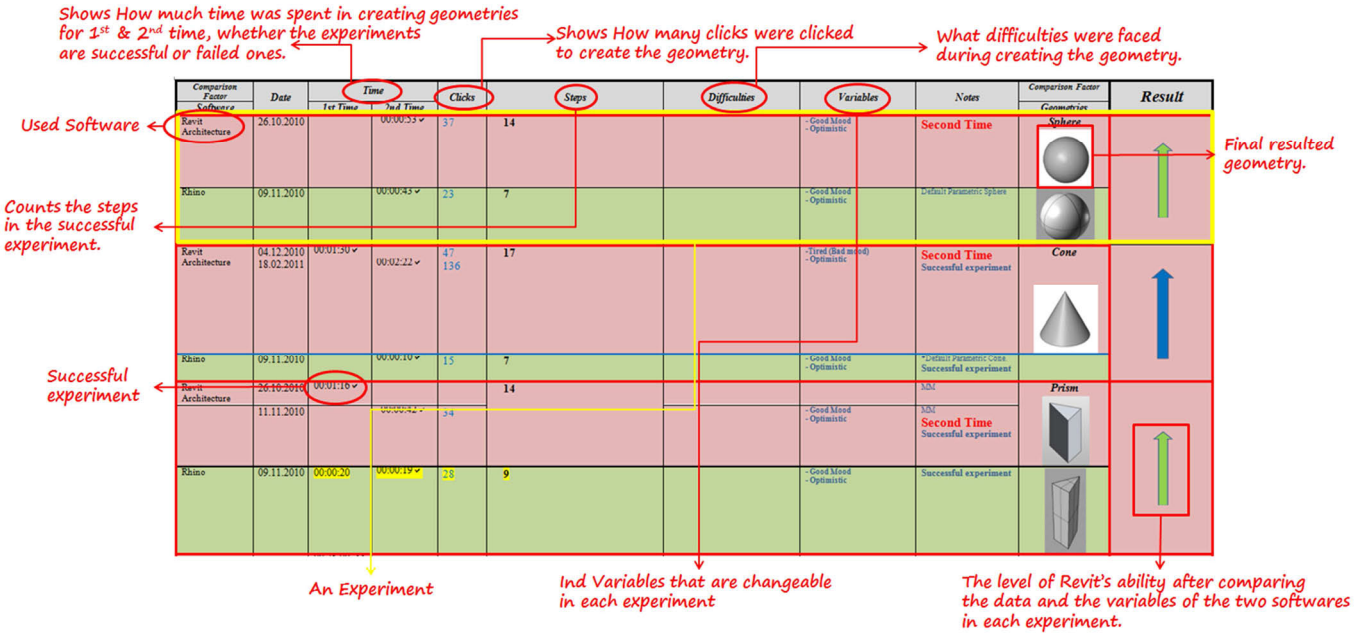


Diagram 11: explains the table that contains the collected data, and the results of the main method.

In the analysis process of the collected data in Diagram 11, the successful or failed result of the experiment is the first DepV that is observed. Time, steps and clicks are considered after ensuring the success of both experiments for the same geometry. If one of the experiments failed, then these variables are not considered in the analysis process.

[46] See page 51.
[47] See Appendix E.

Independent Variables are considered at the final step of the analysis process. They lead to the reasons of the experiment's failure or success. The following diagrams are examples of the strategy that was followed in analyzing the collected data, and can be found in Appendix C.1.

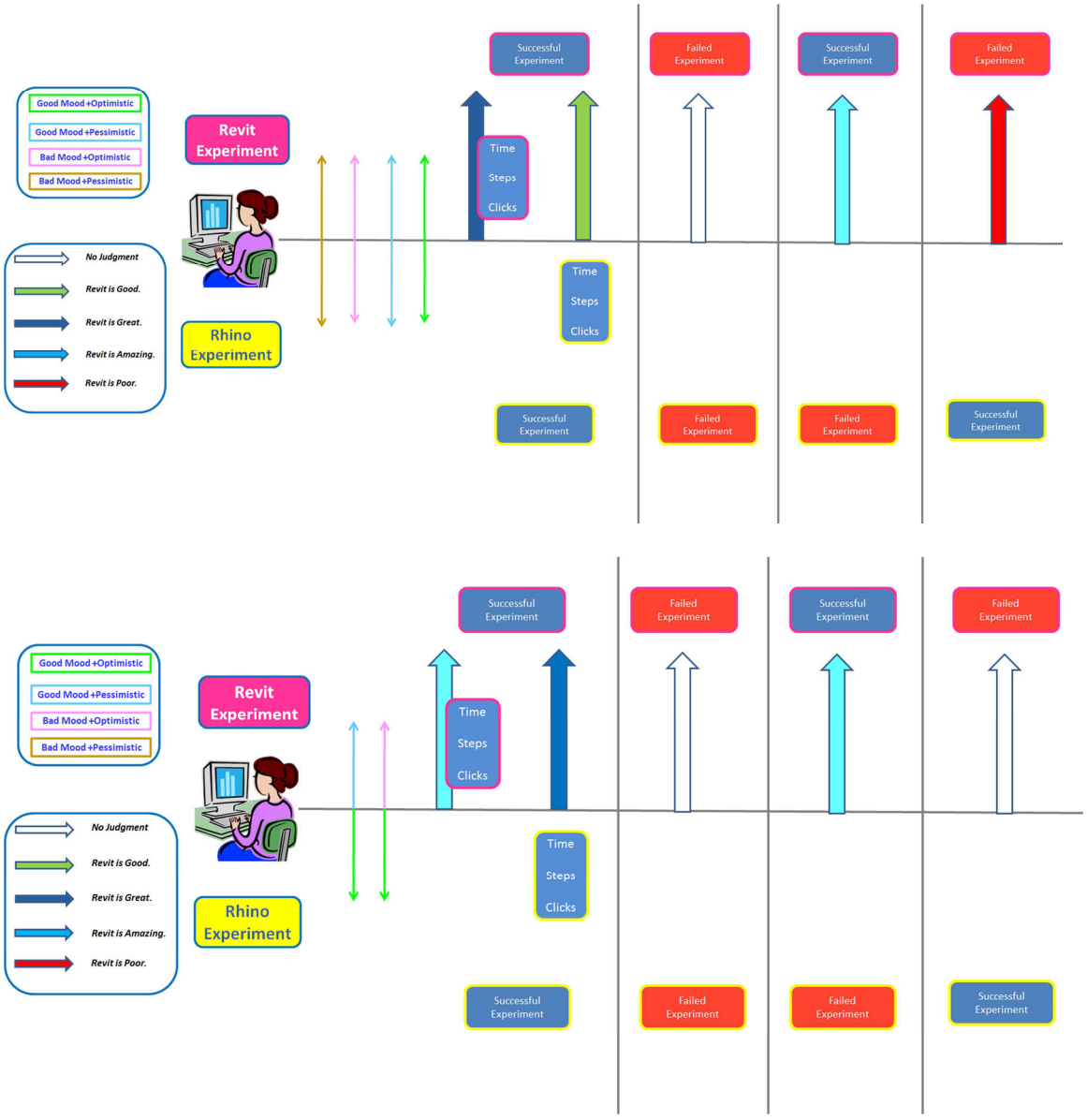


Diagram 12: Illustrates the strategy that was used in analyzing the results of each experiment.

The previous diagrams illustrate five types of result: *Revit is Incredible, Revit is Great, Revit is Good, Revit is Poor and neutral result*. Each of these results is depending on specific criteria as follows:

- **Revit has *Incredible* ability:** means that Revit is able to create the geometry much better than Rhino. Revit in that case excelled Rhino in the success of the experiment, or excelled Rhino in creating the geometry in less time with fewer steps and clicks in spite of the poor IndVs that the participant or the experiment has.
- **Revit has *Great* ability:** means that Revit is able to create the geometry with equivalent abilities with rhino or better. Revit in that case exceeded Rhino in the success of the experiment in spite of the equality of the IndVs for the two softwares, or it succeed in the experiment as well as Rhino despite the poor IndVs that the participant or the experiment has during the work on Revit.
- **Revit has *Good* ability:** means that Revit is able to create the geometry, but not better than Rhino. In that instance, Revit exceled Rhino in the success of the experiment or achieved the experiment in less time with fewer steps and clicks because of the good IndVs that the participant or the experiment has in the both cases.
- **Revit has *Poor* ability:** means that Revit is not able to create the geometry. In that case Revit did not succeed in the experiment in spite of the good or equal

IndVs that the participant or the experiment has in comparing with the IndVs during the work on Rhino.

- **The neutral result:** means that the researcher cannot judge Revit because the two softwares were not able to create the geometry.

The next table summarizes the previous criteria and the strategy that was followed in the analysis process:

Step 1	**Step 2**		
Observe the experiment result (Successful/ Failed).	If two experiment are successful	If one of the experiment are failed	If two experiments are failed
Step 3	Compare time, steps and clicks. Consider the independent variables.	Ignore time, steps and clicks. Consider the independent variables.	NA
Step 4	If Revit has ***Shortest*** time, ***Fewest*** steps and clicks + Better IndV	If Revit ***Succeeded*** + Better IndV	Revit has ***Good ability*** in IGP
	If Revit has ***Longest*** time, ***More*** steps and clicks + ***Better*** IndV		Good ability
	If Revit has ***Shortest*** time, ***Fewest*** steps and clicks + ***Worse*** IndV	If Revit ***Succeeded*** + ***Worse*** IndV	Incredible ability
	If Revit has ***Longest*** time, ***More*** steps and clicks +***Worse*** IndV		Great ability
	If Revit has ***Shortest*** time, ***Fewest*** steps and clicks + ***Equal*** IndV	If Revit ***Succeeded*** + ***Equal*** IndV	Great ability
	If Revit has ***Longest*** time, ***More*** steps and clicks + ***Equal*** IndV		Good ability
		If Revit ***Failed*** + ***Equal*** IndV	Poor ability
		If Revit ***Failed*** + ***Better*** IndV	Poor ability
		If Revit ***Failed*** + ***Worse*** IndV	NA

Table 13: The strategy of the analysis process in the main method.

4.1.3. Results of the Main Method

In this section, the results of the main method are presented and explained in detail. The qualitative data was analyzed using the analysis strategy that was described in the previous section. In addition, the quantitative data was analyzed using Descriptive statistics. Descriptive Statistics "*are used to describe the basic features of the data in a study. They provide simple summaries about the sample and the measures. Together with simple graphics analysis, they form the basis of virtually every quantitative analysis of data.*"(Social Research Methods 2006). It was also used in the analysis process because only six people are participated in both methods: main and confirmation method.
In the descriptive statistics analysis process, the Mean time and the Mean number of steps and clicks were calculated to identify the average value for each software's experiment in each geometry category. Standard Deviation is also calculated to confirm the validity of mean values.

The Table 14 shows the final results of the main method's experiments. The results demonstrate the success of Revit Architecture in most of the experiments of IGP. Revit Architecture software was able to achieve 84% of the selected geometries. It succeeded in creating preliminary solids, secondary surfaces, and complex surfaces, but it failed in generating some secondary solids, and the complex solid. It can be noticed also that Revit Architecture showed a Good ability in IGP stage with more than 50%, and proved Great and Incredible abilities in more than 30% of the experiments.

Geometry	Total	Ability Level				
		Incredible	Great	Good	Poor	NA
Preliminary solids	8	0	2	6	0	0
Secondary solids	9	3	1	2	2	1
Complex Solids	1	0	0	0	1	0
Preliminary Surfaces	3	0	1	2	0	0
Secondary Surfaces	3	0	0	3	0	0
Complex Solids	1	0	1	0	0	0
Total	25	3	5	13	3	1
Percentage	100	12	20	52	12	4

Table 14: demonstrates the abilities that Revit Architecture showed in the experiments of the main method.

The next chart illustrates the ability of Revit Architecture in creating each category of geometries. These categories are arranged in the chart according to the chronology of the creation process. It can be noticed that Revit Architecture showed good ability in creating the preliminary solids, whereas it showed difficulties in creating the secondary and complex solids. The success of Revit in the first category is related to the simplicity of the preliminary solids. However, its failure in creating some of secondary and complex solids is due to the lack of user's experience in using Revit Architecture.

The apparent success in the rest of the geometry categories is probably related to the experience of using Revit that was gained by the researcher during the methodology process which enabled her to discover new abilities in Revit Architecture.

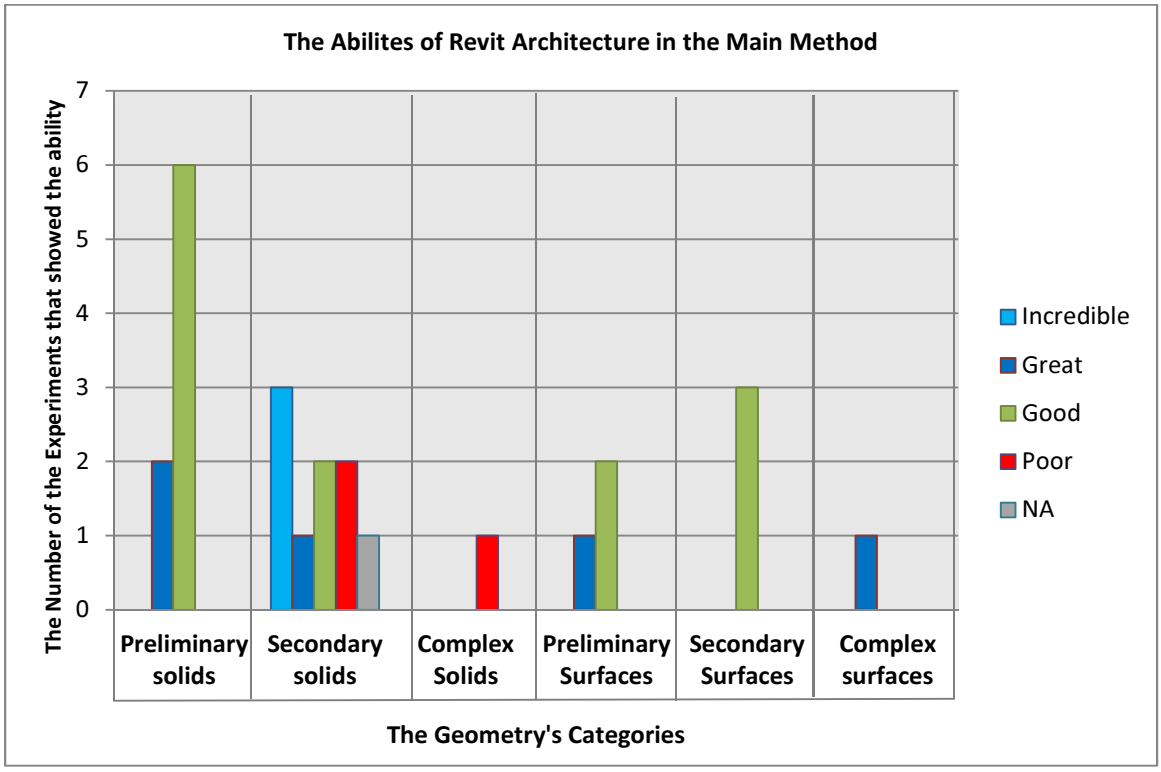


Chart 6: shows the ability of Revit Architecture in creating each category of geometries.

4.1.3.1. Time, Steps & Clicks Results

Despite the obvious success that Revit Architecture achieved in creating about 88% of selected geometries, Rhinoceros proves its superiority on Revit. Not only because it created 100% of the selected geometries, but also because of the short time that was spent in achieving this percentage. The experiments in Revit Architecture lasted about 23 hours to achieve the 88% of the geometries, while in Rhino the experiments took approximately three hours to create the entire list. Additionally, one failed trial confronts two successful trials in Revit, whereas one failed trial parallel 29 successful trials in Rhino. This concludes that the probability of a failed experiment occurrence in Revit Architecture is

1:2, which is a high proportion if compared with the same probability in Rhinoceros which is 1:29.

In the case of time, ***50 minutes*** of wasted time in Revit confronts ***20 minutes*** of productive time in the same software, whereas ***30 minutes*** of wasted time in Rhino parallel ***150 minutes*** of productive time in the same software as seen in Chart 7. The researcher worked on Rhinoceros about ***1/3*** of time that was spent to work on Revit. In addition, **60%** of the time that was spent on Revit was in the failed trials. No time was wasted on the creation process of the surface geometries, because of the progression of the user's experience in using Revit Architecture during the research period.

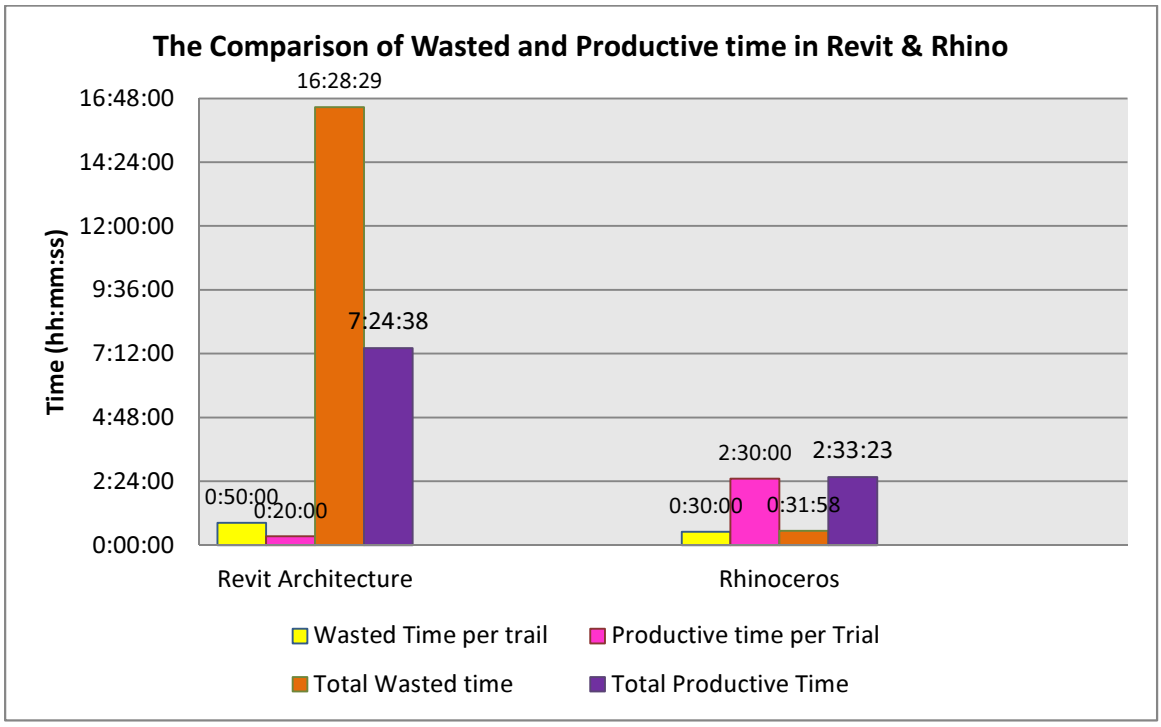


Chart 7: illustrates the difference of wasted and productive time in Revit & Rhino.

The next tables illustrate the comparison between Revit Architecture and Rhinoceros in the total and the average of time, steps, and clicks. In the case of the total time comparison, it was found that the total time of Rhinoceros's trials was ***less by one-third*** of the total time of Revit's trials as well as the case of the average time.

Total Values	Revit Architecture			Rhinoceros		
Geometry	**Time**	**Steps**	**Clicks**	**Time**	**Steps**	**Clicks**
Preliminary solids	7:11:20	203.00	2582.00	0:11:40	73.00	248.00
Secondary solids	11:57:16	191.00	5510.00	1:01:24	181.00	2853.00
Complex Solids	0:52:47	0.00	0.00	0:23:26	66.00	1208.00
Preliminary Surfaces	2:04:59	89.00	5367.00	0:24:45	74.00	276.00
Secondary Surfaces	1:25:31	86.00	3722.00	0:19:22	64.00	590.00
Complex Solids	0:21:14	33.00	1629.00	0:44:44	34.00	605.00
Total	23:53:07	602.00	18810.00	3:05:21	492.00	5780.00

Table 15: illustrates the comparison between Revit Architecture and Rhinoceros in the total of time, steps, and clicks

Average Values	Revit Architecture			Rhinoceros		
Geometry	**Time**	**Steps**	**Clicks**	**Time**	**Steps**	**Clicks**
Preliminary solids	0:14:52	25.38	184.43	0:01:10	9.13	31.00
Secondary solids	0:34:09	27.29	612.22	0:06:08	20.11	285.30
Complex Solids	0:26:23	0.00	0.00	0:05:51	33.00	604.00
Preliminary Surfaces	0:41:40	29.67	1789.00	0:08:15	24.67	92.00
Secondary Surfaces	0:28:30	28.67	1240.67	0:06:27	21.33	196.67
Complex Surfaces	0:10:37	33.00	1629.00	0:14:55	34.00	605.00
Total	0:26:02	24.00	909.22	0:07:08	23.71	302.33

Table 16: illustrates the comparison between Revit Architecture and Rhinoceros in the average of time, steps, and clicks

In the comparison process between the total and the average number of steps between Revit and Rhinoceros, the secondary and complex solids categories were excluded as illustrated in both Table 15 and Table 16 with red colored cells, because of the three failed experiments in these categories. In the instance of failed experiments, the steps are not documented and counted, so the result would have been inadequate if these categories were involved in the comparison. According to the comparison of results, the total number of steps in Rhino's experiments is 7:9 the total number of steps in Revit. A similar ratio which is 6:7 was also found in comparing the average number of the steps in the both software. This means that Rhinoceros needs the three-quarters of Revit's steps to perform the same tasks. At the same conditions, it was detected that Rhinoceros consumed the quarter number of clicks that were used in Revit. Chart 8, Chart 9, Chart 10 and Chart 11 demonstrate the comparisons between the total and the average number of steps and clicks between Revit and Rhino. The dashed bars indicate to the eliminated solid categories from the comparisons.

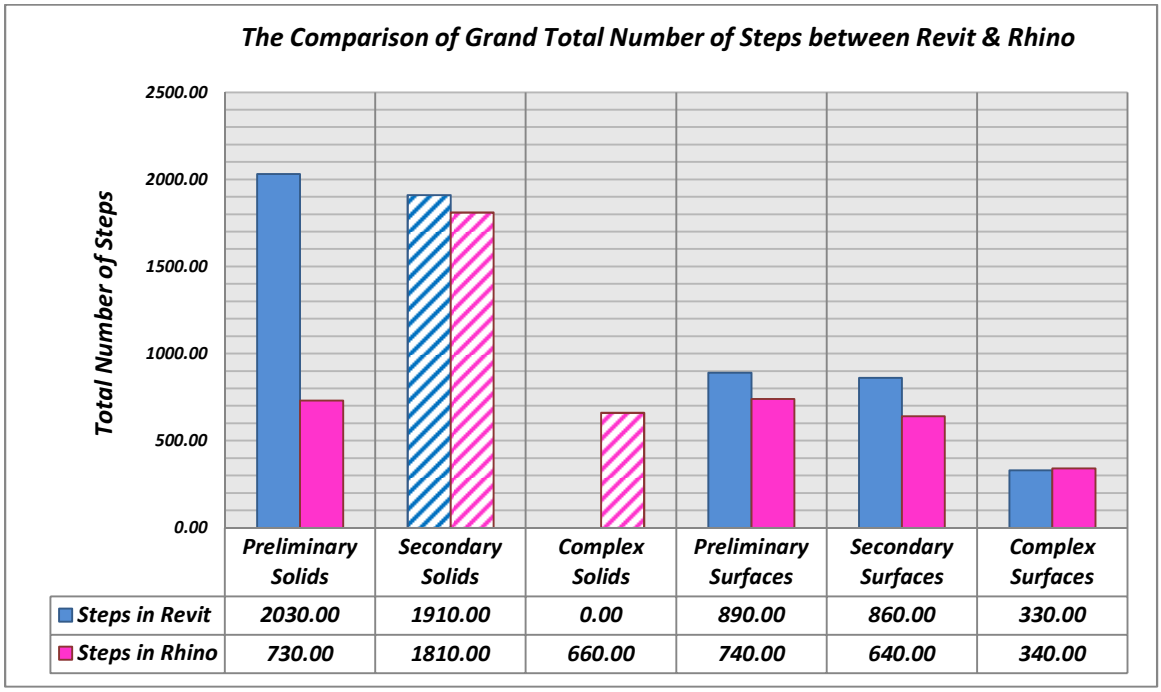


Chart 8: The comparison of grand total number of Steps between Revit Architecture and Rhinoceros.

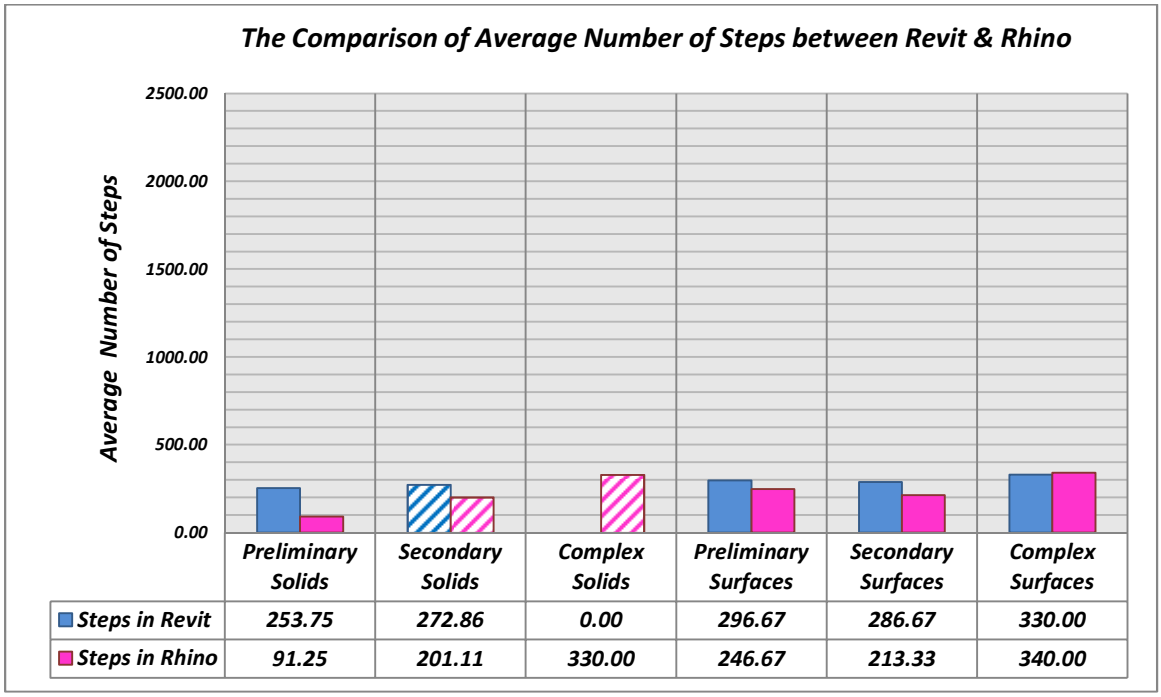


Chart 9: The Comparison of Average Number of Steps between Revit Architecture and Rhinoceros.

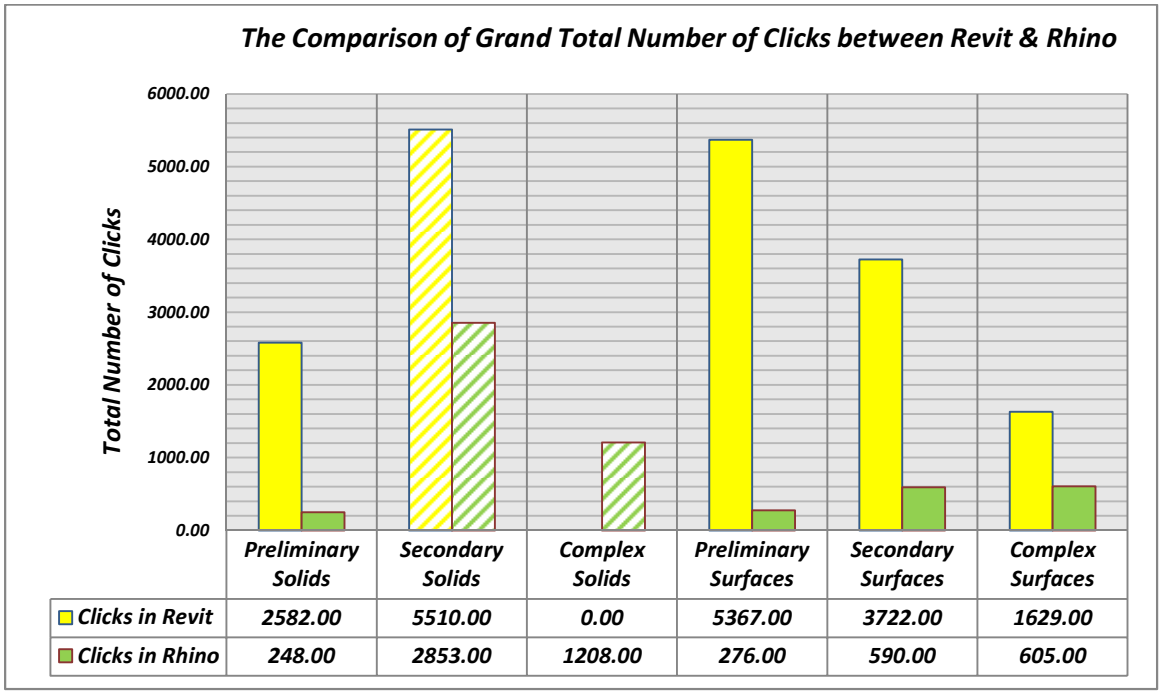


Chart 10: The comparison of grand total number of clicks between Revit Architecture and Rhinoceros.

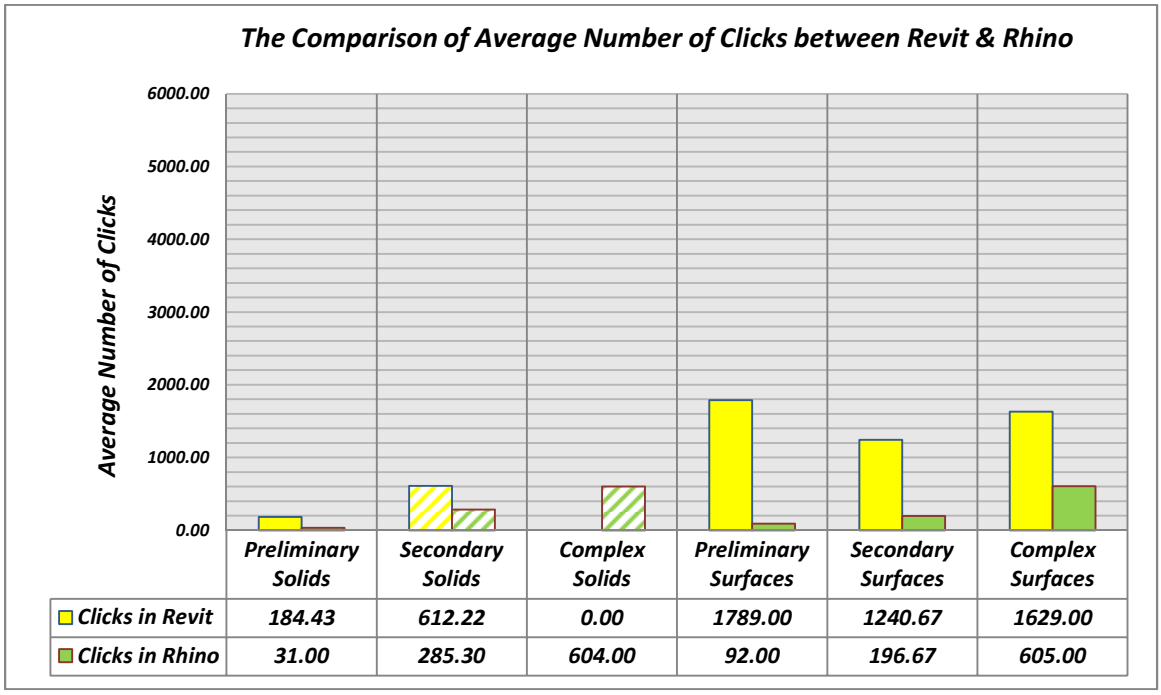


Chart 11: The Comparison of Average Number of clicks between Revit Architecture and Rhinoceros.

4.2. Analysis Process of the Confirmation Method

In the confirmation method, the five participants worked on 33 trials of 12 experiments in Revit Architecture as well as in Rhinoceros.

Student's Experiments		Revit Architecture			Rhinoceros			Total Number of Experiments
Geometry	Number of geometries	Successful	Semi-Successful	Failed	Successful	Semi-Successful	Failed	
Preliminary Solids	1	4	0	0	4	0	0	8
Secondary Solids	1	1	1	2	4	0	0	8
Complex Surfaces	1	0	2	2	2	1	1	8
Total	3	5	3	4	10	1	1	24

Table 17: Shows the number of successful and failed experiments that were done by the students for each software.

It is noticeable the significant difference in the achievement of the students in creating the three selected geometries as shown in Table 17. In Revit, the students succeeded in more than 41% of the experiments, while in Rhinoceros they accomplished more than 80% of the experiments. In other words, Revit Architecture made the half achievement of Rhinoceros in confirmation method.

In the case of comparing between successful and failed trials in the Table 18, it can be observed that the students worked on ***16 trials*** in Revit Architecture. They only succeeded in ***31%*** of these trials to achieve the ***five*** successful experiments in

approximately ***two hours and a half***, whereas they worked on ***17 trials*** to accomplish the 80% of the experiments in about an ***hour and a half***. This indicates that ***for each failed*** trial in Revit Architecture, there is ***one successful trial*** with rate of ***12 minutes*** of wasted time to ***6 minutes*** of productive time. On other hand, ***one failed*** trial in Rhinoceros confronts ***three successful trials*** with the rate of ***9 minutes*** of wasted time to ***2.5 minutes*** for productive time. It is also worth mentioning that the students took an average time of 9 minutes to work on each trial in Revit, whereas they spent an average of 4 minutes in each trial in Rhinoceros.

Student Trials	Revit Architecture			Rhinoceros		
Geometry	**Successful**	**Semi-Success**	**Failed**	**successful**	**Semi-Success**	**Failed**
Preliminary solids	4	0	0	4	0	0
Secondary solids	1	1	2	4	0	0
Complex Surfaces	0	2	6	4	1	4
Total	5	3	8	12	1	4
Time spent	0:20:53	0:28:01	1:35:13	0:28:38	0:03:12	0:35:06

Table 18: compares between successful and failed trials in the confirmation method.

In the next chart, it is remarkable that Rhinoceros has more trials than Revit Architecture. However, the participants of that method spent half of the Revit's time on the 17 trials in Rhinoceros, and succeed in more than 80% of the experiments.

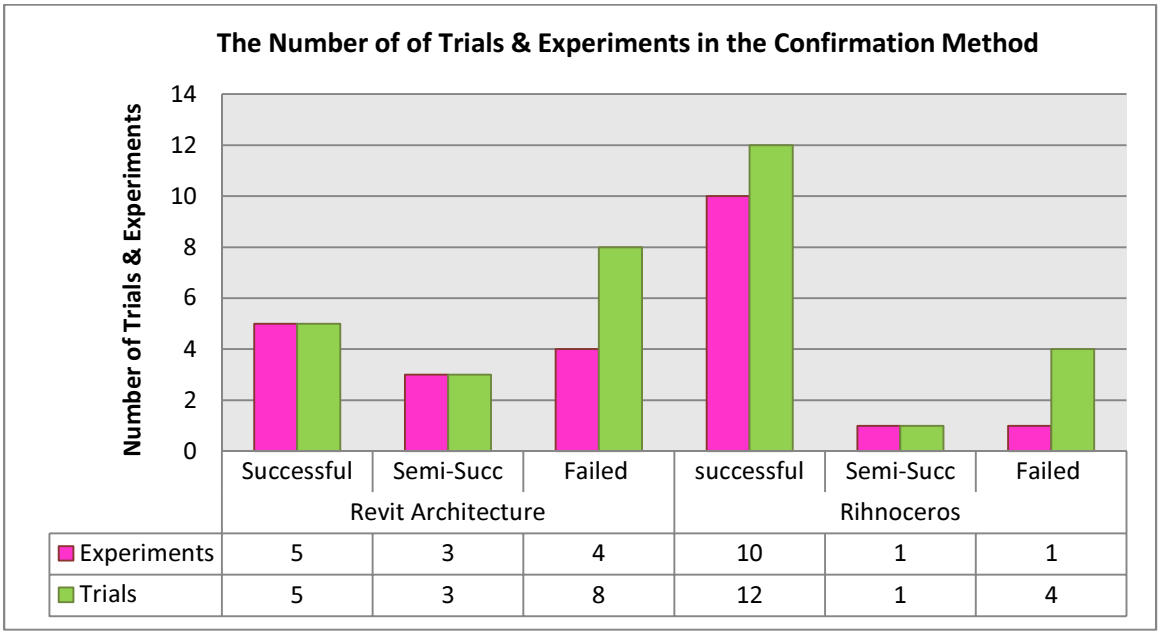


Chart 12: shows the difference in the number of the trials and experiments between Revit Architecture and Rhinoceros in the confirmation method.

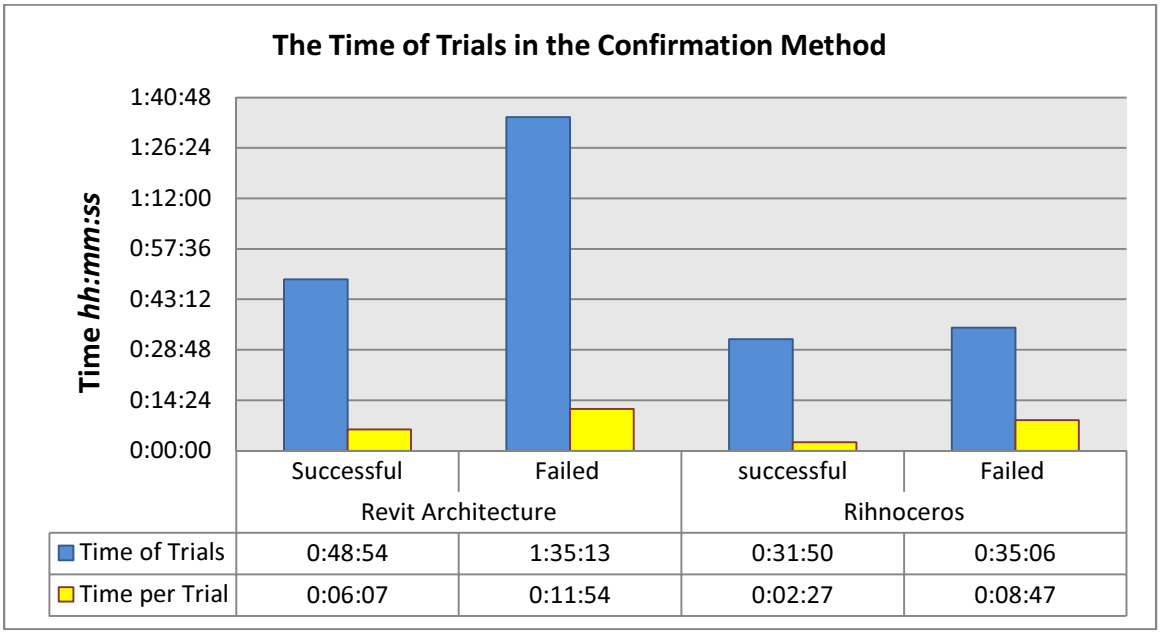


Chart 13: Shows the difference in the time of trials between Revit Architecture and Rhinoceros.

In order to obtain an accurate judgment and an explanation of the results in the confirmation method, IndVs should be considered as were considered in the main

method. The pre-questionnaire[48] that the students answered before they work on the experiments in the confirmation method provided the researcher with the IndVs of the experiments. The consideration of these IndVs validates the results of the confirmation method.

4.2.1. The Independent Variables in Confirmation Method

The independent variables in the confirmation method are also divided into constant IndVs and changeable IndVs. The constant IndVs are the same for all participants and cannot be changed, such as work place environment, computer's capabilities and software interface. On another hand, changeable IndV are different from one participant to another. Table 9 lists these variables in the confirmation method:

<table>
<tr><th colspan="3">Constant IndV</th><th>Changeable IndV</th></tr>
<tr><td>Work place Environment</td><td colspan="2">Good Environment</td><td>Psychological & Physical Aspects</td></tr>
<tr><td>Computer’s Capabilities</td><td colspan="2">Good Capabilities</td><td>User Attitude</td></tr>
<tr><td rowspan="3">Software Interface</td><td>Rhino</td><td>Revit</td><td>Previous Experience</td></tr>
<tr><td rowspan="2">Useful Interface</td><td rowspan="2">Moderate Interface</td><td>Previous Use in Architectural Design</td></tr>
<tr><td>User Expectations</td></tr>
</table>

Table 19: shows the IndVs in the confirmation method

The next diagrams illustrate all the IndV of the confirmation method, and demonstrates the relationship between these variables. It also shows the constant and the changeable

[48] See Appendix G.1.

variables, and the possible results of each one. For example, user's attitude has two possible outcomes. If the user desired to learn Revit/ Rhino, and was enjoying the use of it, then s/he has a good attitude towards the software. The good attitude affects positively on the performance of the user. This positive effect contributes effectively to the result of the experiment.

User Attitude (Wanted to learn the software+ Enjoys using it) >

Good attitude **>** ***Successful Result***

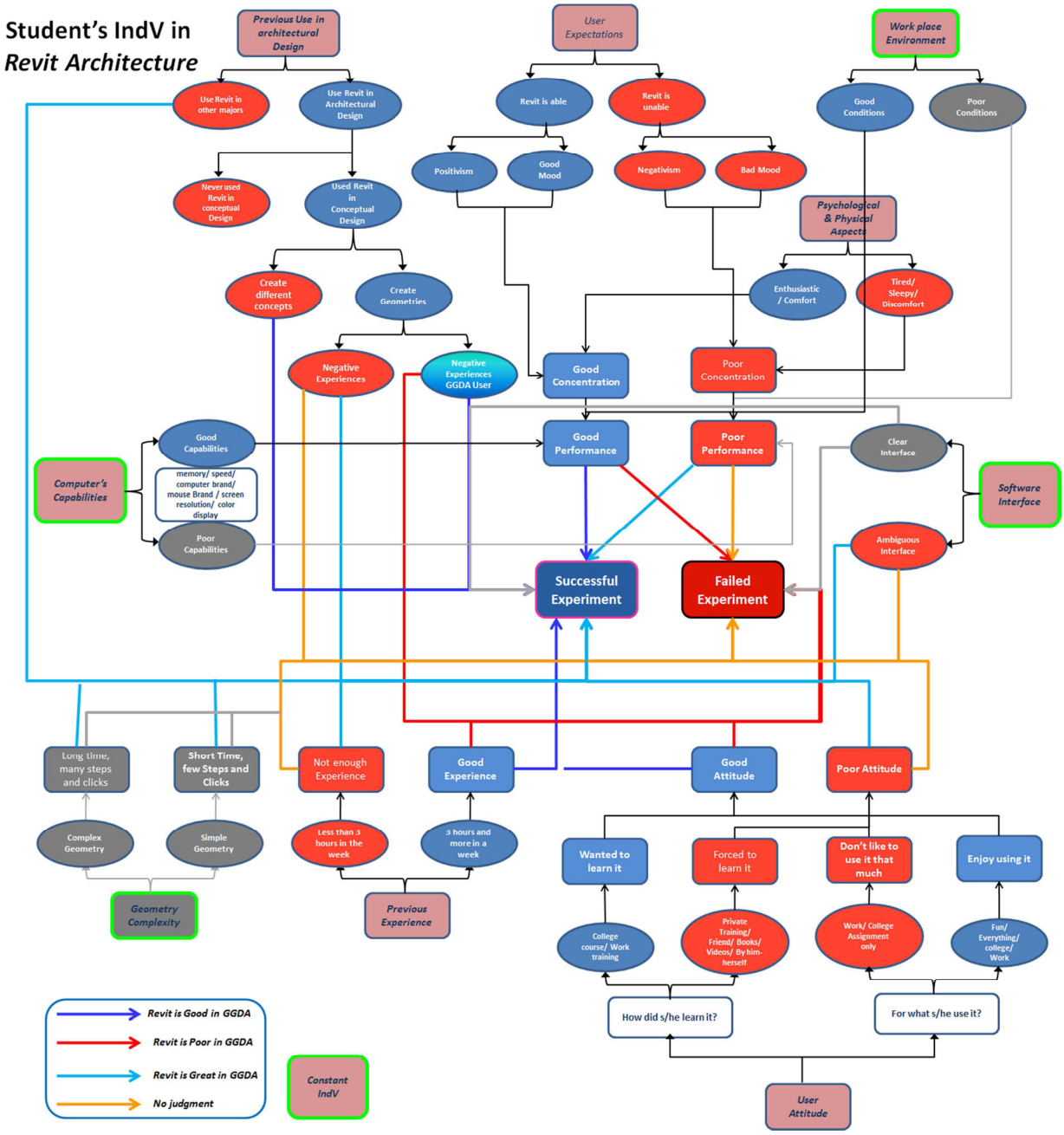


Diagram 13: The IndVs in the confirmation method and the correlation between these variables and the possible results of the experiments in Revit Architecture.

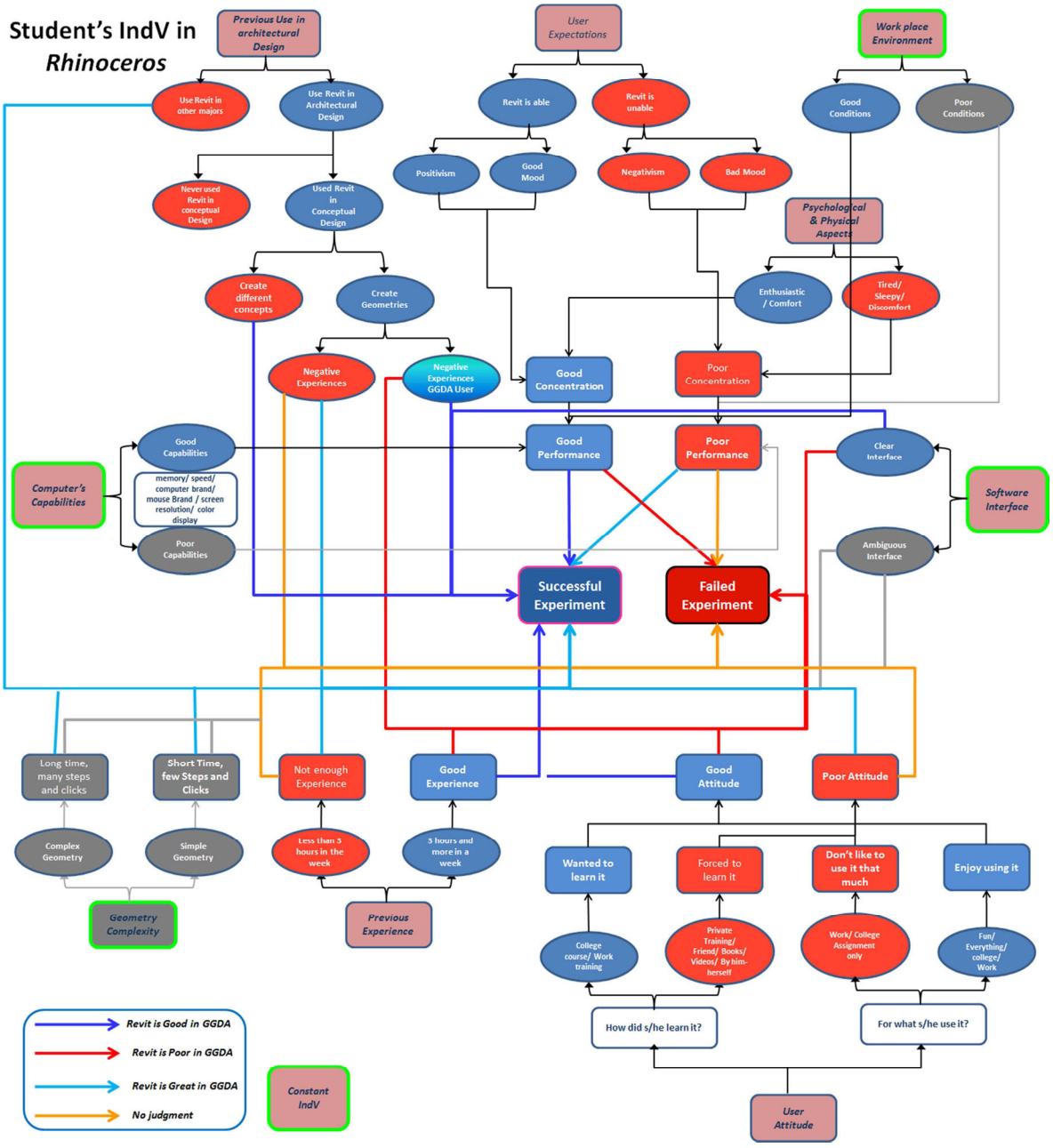


Diagram 14: The IndVs in the confirmation method and the correlation between these variables and the possible results of the experiments in Rhinoceros.

According to the results of the pre questionnaire[49], the participants in the confirmation method do not have good experience in using Revit Architecture, while they consider themselves experts in using Rhinoceros. The good experience in using Rhinoceros might have effects on the results of the experiments. It can be noticed that the student accomplished good achievements in Rhino experiment. This experience provides the students with previous knowledge about the techniques that might help to create the geometries. This previous knowledge makes them work faster in the experiments of Rhino than in the experiment of Revit. The next chart illustrates the difference in the experience of the students in Revit Architecture and Rhinoceros depending on the pre-questionnaire's results that included in Appendix G.2.

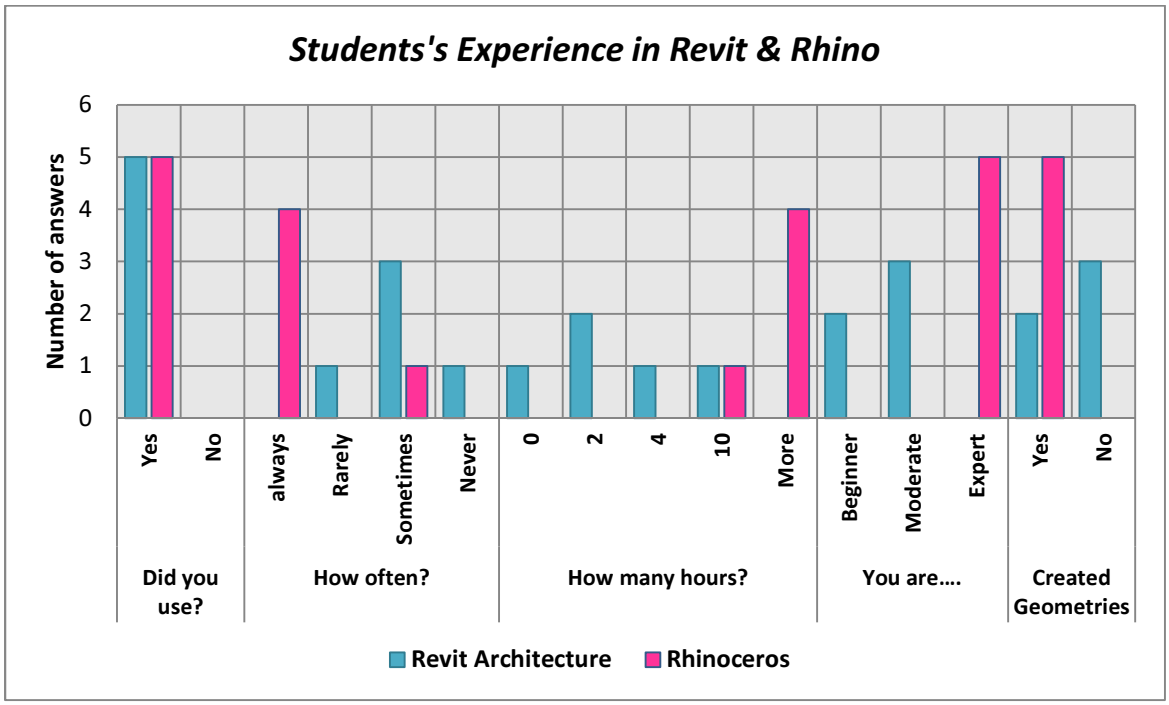


Chart 14: illustrates the difference in the experience of the students in Revit Architecture and Rhinoceros depending on the pre-Questionnaire's results.

[49] See Appendix G.2.

In addition to the participant's experience, the ambiguous interface of Revit and the poor attitude of the participants towards Revit might have an effect also on the time. The following chart clarifies the difference of student's attitudes and their expectations towards both softwares according to the pre-questionnaire.

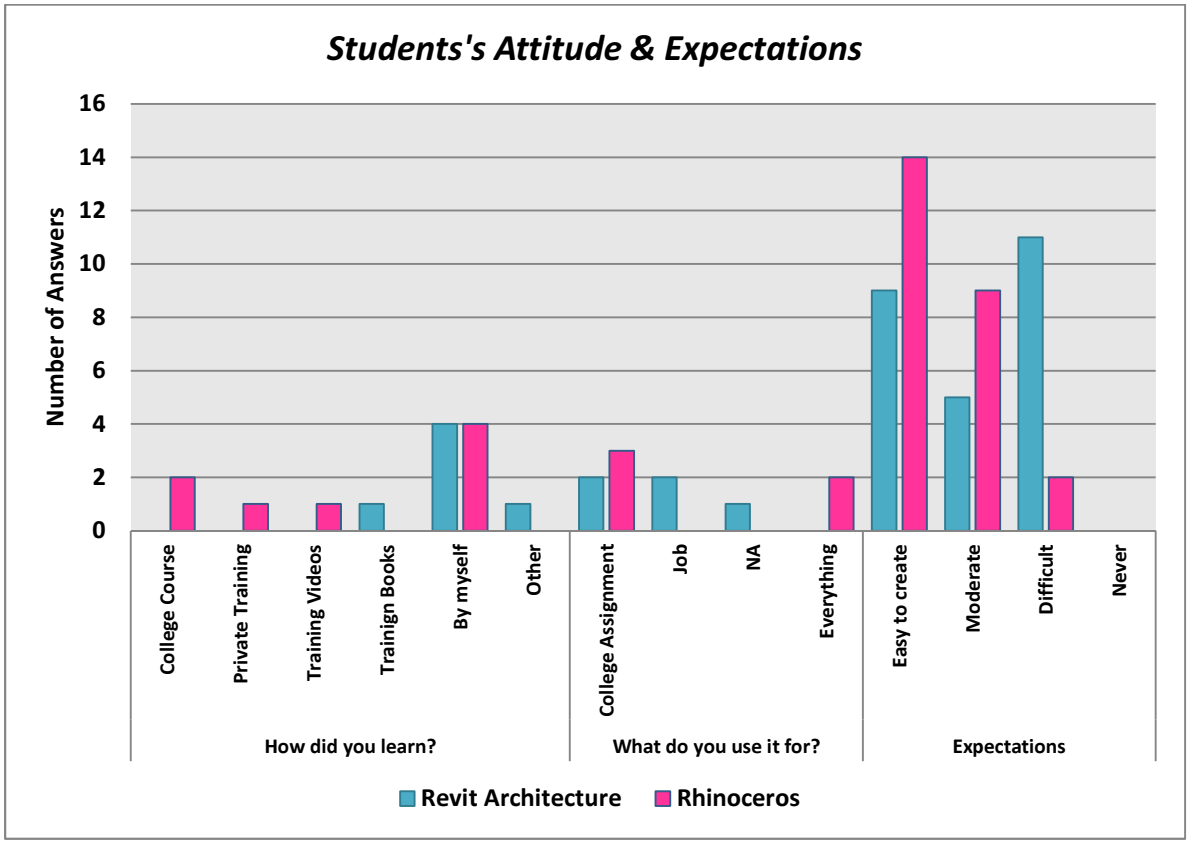


Chart 15: clarifies the difference of student's attitudes and their expectations towards both softwares according to the pre-questionnaire.

4.2.2. Analysis Strategy in the Confirmation Method

The same strategy of analyzing the collected data in the main method has been followed in the analysis process of the confirmation method. This strategy is dependent on analyzing the IndVs for each participant. These IndVs include: psychological and physical aspects, attitude, previous experience and expectations of the participant. Diagram 15 explains the table that included in Appendix F. This table contains the collected data in the confirmation method, the IndVs of the participants and the result of the analysis process.

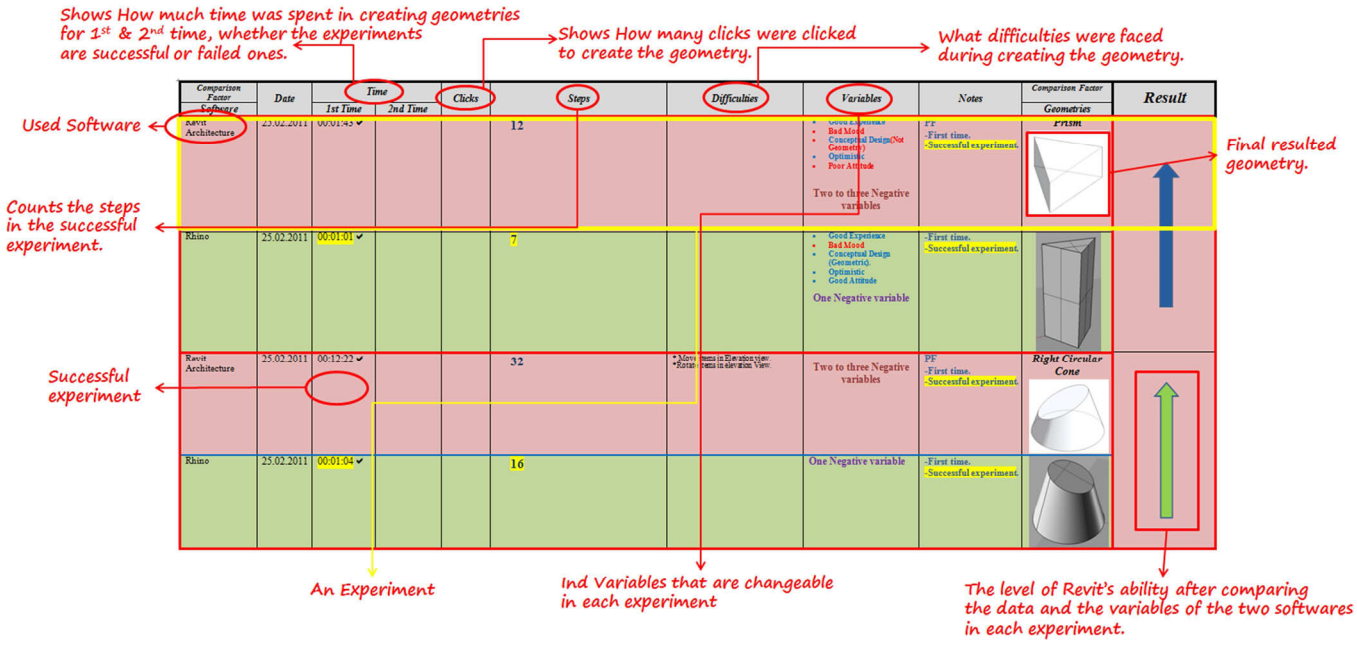


Diagram 15: explains the table that contains the collected data, and the results of the confirmation method.

In the analysis strategy of the IndV in the confirmation method, participants are divided into four categories dependent on the IndV as shown in Diagram 16. These categories include:

a) **All IndVs are positive category:** In this category, the IndVs of the participant are all positive. For instance, a participant who: *has a good previous experience in Revit, feels comfort, used Revit in conceptual design phase, used Revit in creating geometries for design concept, feels optimistic about the results of the experiment, and has a good attitude* belongs to this category because s/he has all positive variables in that case.

b) **One negative IndV category:** One negative variable makes the participant belong to this category. An example of this participant: *has a good previous experience in Revit, feels discomfort, used Revit in conceptual design phase, used Revit in creating geometries for design concept, feels optimistic about the results of the experiment, and has a good attitude.*

a) **Two or three negative IndVs category.**
b) **Four or more negative IndVs category.**
c) **All IndV are negative category.**

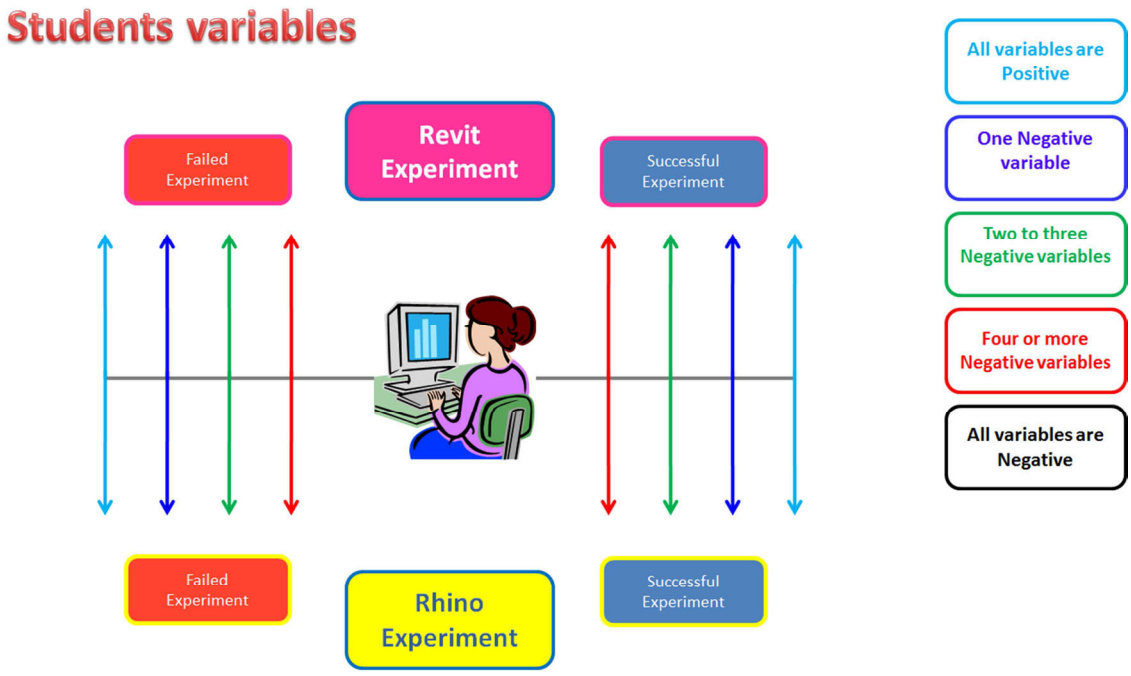


Diagram 16: illustrates the structure of the analysis process for the collected data in the confirmation method.

The analysis process of the collected data is the same process in the main method. The result of the experiment is the first step of the analysis. In the second step, the DepVs: time, steps and clicks are considered in the case that both experiments in Revit and Rhino for the same geometry are successful. The consideration of IndVs is the final step of the analysis process. The participant in that step is identified to which category s/he is belonging to. The following diagrams are examples of the strategy that was followed in analyzing the collected data, and can be found in Appendix C.2.

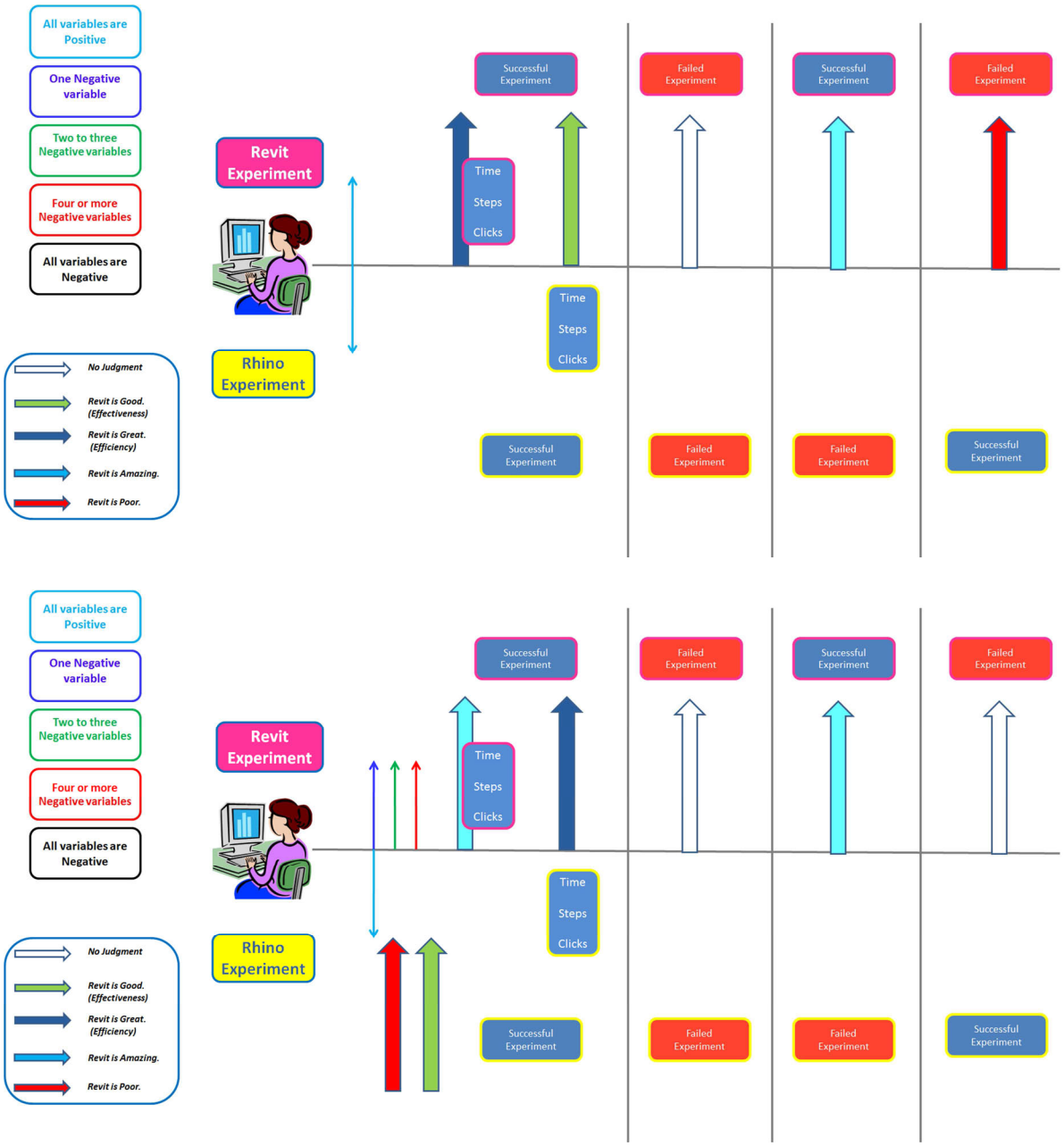


Diagram 17: shows two of the diagrams that were used in analysis the results of the confirmation method's experiments.

The next table summarizes the strategy that was followed in the analysis process of the confirmation method:

Step 1	**Step 2**		
Observe the experiment result (Successful/ Failed).	If two experiment are successful	If one of the experiment are failed	If two experiments are failed
Step 3	Compare time, steps and clicks. Consider the independent variables.	Ignore time, steps and clicks. Consider the independent variables.	NA
Step 4	If Revit has ***Shortest*** time, ***Fewest*** steps and clicks + Better IndV	If Revit ***Succeeded*** + Better IndV	Revit has ***Good ability*** in IGP
	If Revit has ***Longest*** time, ***More*** steps and clicks + ***Better*** IndV		Good ability
	If Revit has ***Shortest*** time, ***Fewest*** steps and clicks + ***Worse*** IndV	If Revit ***Succeeded*** + ***Worse*** IndV	Incredible ability
	If Revit has ***Longest*** time, ***More*** steps and clicks +***Worse*** IndV		Great ability
	If Revit has ***Shortest*** time, ***Fewest*** steps and clicks + ***Equal*** IndV	If Revit ***Succeeded*** + ***Equal*** IndV	Great ability
	If Revit has ***Longest*** time, ***More*** steps and clicks + ***Equal*** IndV		Good ability
		If Revit ***Failed*** + ***Equal*** IndV	Poor ability
		If Revit ***Failed*** + ***Better*** IndV	Poor ability
		If Revit ***Failed*** + ***Worse*** IndV	NA

Table 20: The strategy of the analysis process in the confirmation method.

4.2.3. Results of the Confirmation Method

The analyzing process of the qualitative and quantitative data in the main method is also pursued for the data of the confirmation method. The analyzing of the qualitative data of IndV was explained in the previous section, while quantitative data of DepVs are analyzed using the descriptive statistics.

In the tracking of IndV and DepV of the results in Appendix F, it can be noticed that Revit Architecture achieved success in creating three different geometries by the participants. Revit Architecture showed Great ability[50] in creating the preliminary geometry which is the prism, while it proved that it has Good ability in creating the secondary solid "right circular cone" and the complex surface "mobius strip". The software displayed 66% of Great and Good abilities[50], whereas Poor ability[50] had not been showed in this method. The obvious difference in the results of the Table 17 and Table 21 proves the significant impact of the IndVs on the final findings.

Geometry	Total	Incredible	Great	Good	Poor	NA
Preliminary solids	4	0	4	0	0	0
Secondary solids	4	0	0	2	0	2
Complex Solids						
Preliminary Surfaces						
Secondary Surfaces						
Complex Surfaces	4	0	0	2	0	2
Total	12	0	4	4	0	4

Table 21: demonstrates the abilities that Revit showed in the confirmation methods experiments.

[50] See page 116 for the definition of different abilities.

The chart confirms the Great ability that Revit showed in creating the preliminary geometry "the prism". This achievement is related to the simplicity of the geometry. While Revit displayed Good ability in creating the secondary and complex geometries "RC cone and mobius strip". Most of the participants did not succeed completely in creating the mobius strip[51], but their IndVs had justified their inability to create that complex geometry.

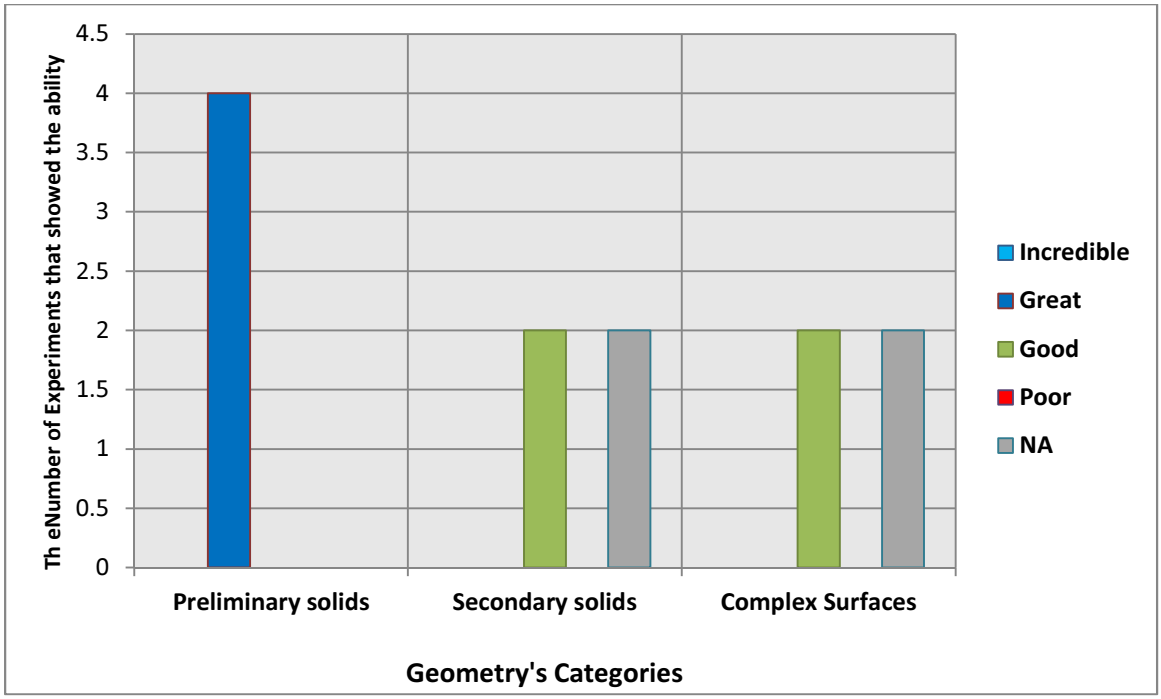


Chart 16: illustrates the abilities of Revit in the experiments of each geometry category in the confirmation method.

4.2.3.1. Time, Steps & Clicks Results

It can be observed in Chart 12 the close number of the trials in both Revit Architecture and Rhinoceros, but the difference in the time is significant and obvious. The students

[51] See Appendix F.

worked on ***16 trials*** in Revit Architecture in ***two hours and a half***, whereas they worked on ***17 trials*** in Rhinoceros in about ***hour and a half***. In addition, ***one failed trial*** confronts ***one successful trial*** in Revit, while ***one failed trial*** in Rhino parallels ***three successful trials***. Accordingly, the probability of failed experiment occurrence is ***1:1*** for Revit Architecture, whereas the probability in Rhinoceros is ***1:3***. Revit's probability in the confirmation method is higher than the same probability in the main method which is ***1:2***, and Rhino's probability in the confirmation method is lower than its probability (***1:29***) in the main method.

In the case of the productive time that was spent in each software, there are adjacent values. However, an apparent difference is detectable in the matter of the wasted time in the two softwares. In Revit Architecture's experiments, the students wasted about ***one hour and a half*** to realize the right ways of creating the geometries, thought they consumed only ***half an hour*** to determine these ways in Rhinoceros. In other words, the participants had ***three*** times the amount of the wasted time in Rhinoceros to configure the suitable techniques in Revit Architecture. Conversely, different results appeared when the time data was analyzed with different aspect. It showed that ***12 minutes*** of wasted time confronts ***6 minutes*** of productive time in Revit with the ratio ***2:1***, whereas ***9 minutes*** of wasted time parallels ***2.5 minutes*** of productive time in Rhino with ***3.6: 1*** ratio as shown in Chart 17. It is notable from the previous ratios that Rhino has high proportion of wasted time than Revit Architecture in spite of the good experience that the participants have in working on Rhinoceros.

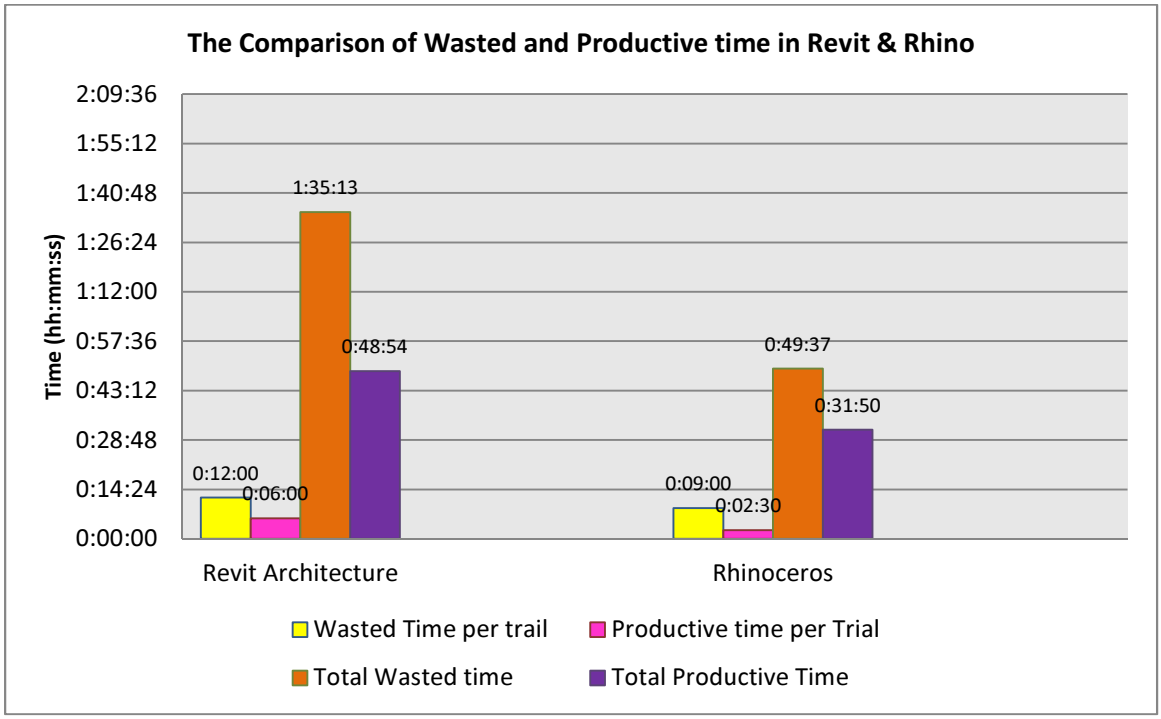


Chart 17: shows the difference of the time between Revit and Rhinoceros in the confirmation method.

The total and the average time of the experiments in the confirmation method are exemplified in Table 23 and Table 23. Additionally, the total and average number of steps of these experiments is included. In the case of click counting, the process did not succeed due to technical problems during the experiment day. Therefore, the clicks number analysis is eliminated from the analysis process.

In the case of the comparison of the total time, Rhinoceros showed superiority in time saving. It saved about 40% of the time that was consumed in working on Revit. In the case of the average time for each experiment, the results demonstrate that the average time to finish an experiment in Rhino equals 44% of the average time for an experiment in Revit. These results also contradict with the results of the comparison between the wasted and productive time for each software.

Total Values	Revit Architecture		Rhinoceros	
Geometry Category	Time	Steps	Time	Steps
Preliminary solids	0:08:31	45.00	0:04:07	33.00
Secondary solids	0:27:13	66.00	0:03:40	67.00
Complex Surfaces	1:48:23	69.00	1:13:40	77.00
Total	2:24:07	180.00	1:21:27	177.00

Table 22: shows the difference between Revit and Rhino in accordance of the total values of time and steps of the experiments of the confirmation method.

Average Values	Revit Architecture		Rhinoceros	
Geometry Category	Time	Steps	Time	Steps
Preliminary solids	0:02:08	11.25	0:01:02	8.25
Secondary solids	0:06:48	16.50	0:00:55	16.75
Complex Surfaces	0:13:33	13.80	0:08:11	15.40
Total	0:07:30	13.85	0:03:23	13.47

Table 23: shows the difference between Revit and Rhino in accordance of the average values of time and steps of the experiments of the confirmation method.

In the instance of comparing the total and average number of steps for each experiment in the confirmation method, it is recognizable the clear proximity in the results. Despite of the contradicted results in the total and average time that was spent in Revit and Rhino, the total and the average number of steps is almost equal in both softwares. The equality in the number of the steps in both softwares is due the lack of experience that the students have in using Revit, and the good experience that they have in using Rhinoceros. The

good experience in using Rhinoceros provides the students with previous knowledge about the steps that might help to create the geometries. Chart 18 and Chart 19 illustrate the comparisons between the total and the average number of steps in Revit Architecture and Rhinoceros in the confirmation method.

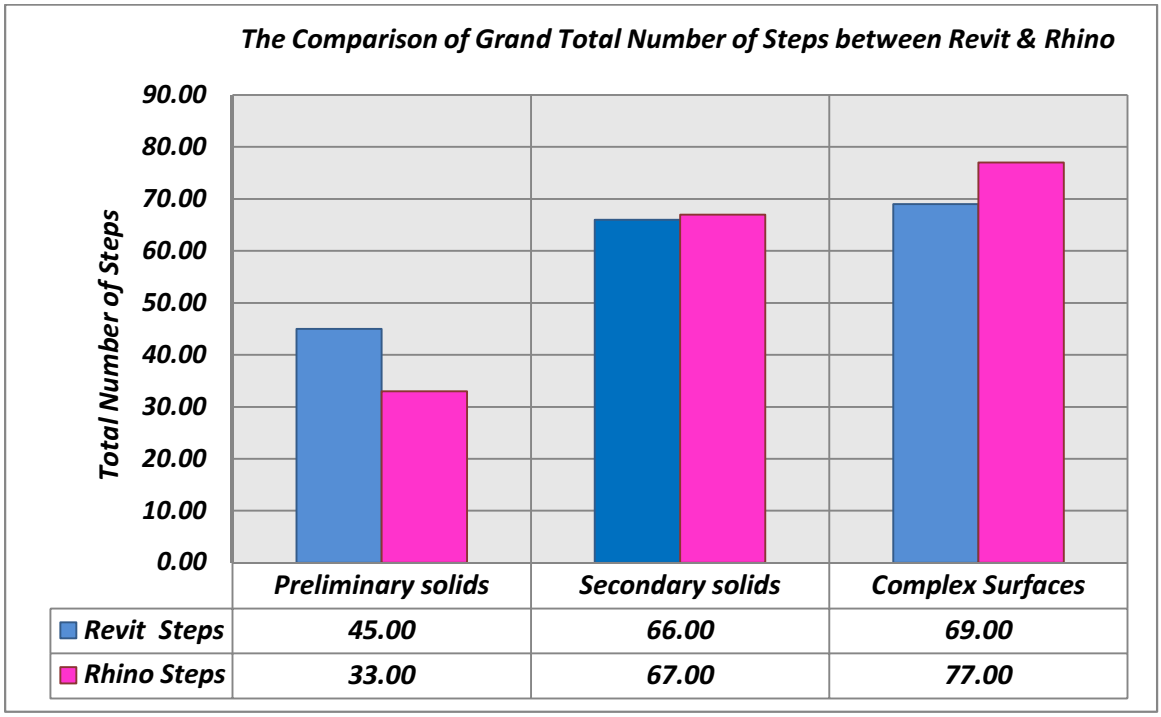


Chart 18: The comparison of grand total number of steps in Revit Architecture and Rhinoceros.

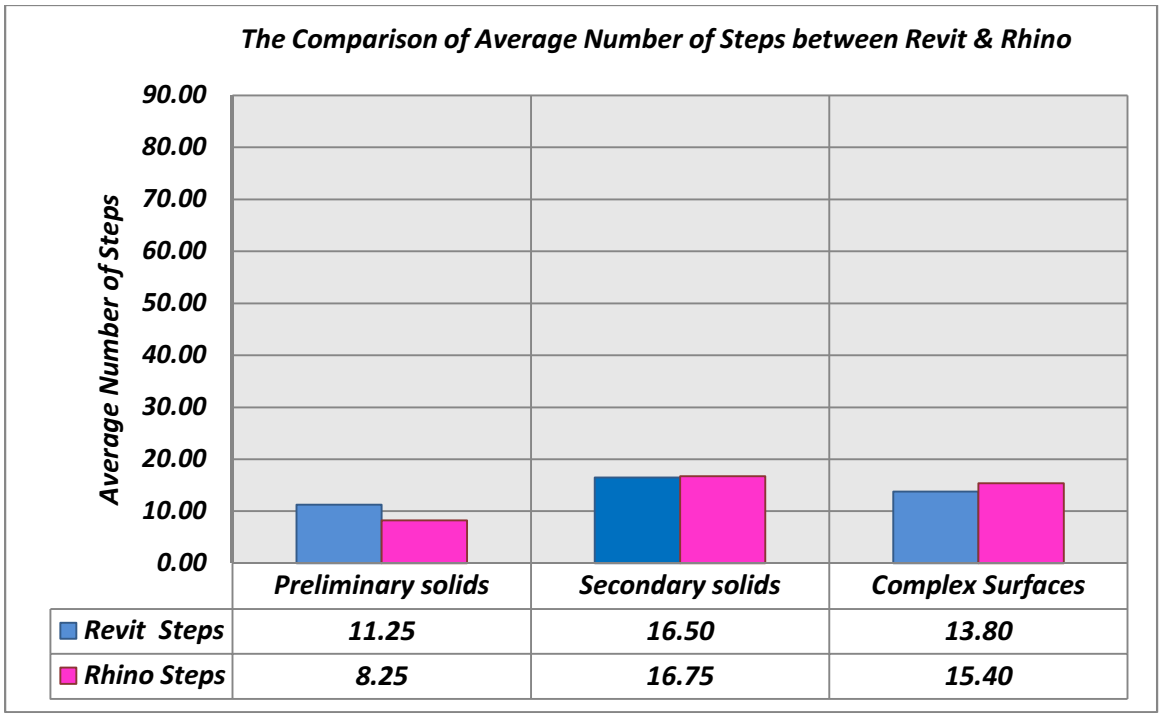


Chart 19: The Comparison of average number of steps in Revit Architecture and Rhinoceros.

Chapter 5. Conclusion

The purpose of this thesis as stated earlier is to investigate the capabilities of Revit Architecture as one of BIM applications with a specific design approach GGDA. This study examines the reliability of Revit Architecture, and awares the architects and designers who adopted GGDA of the compability and reliability of the software. This awareness provides them with explicit idea about the software and enables them to judge its appropriateness with their ways of thinking.

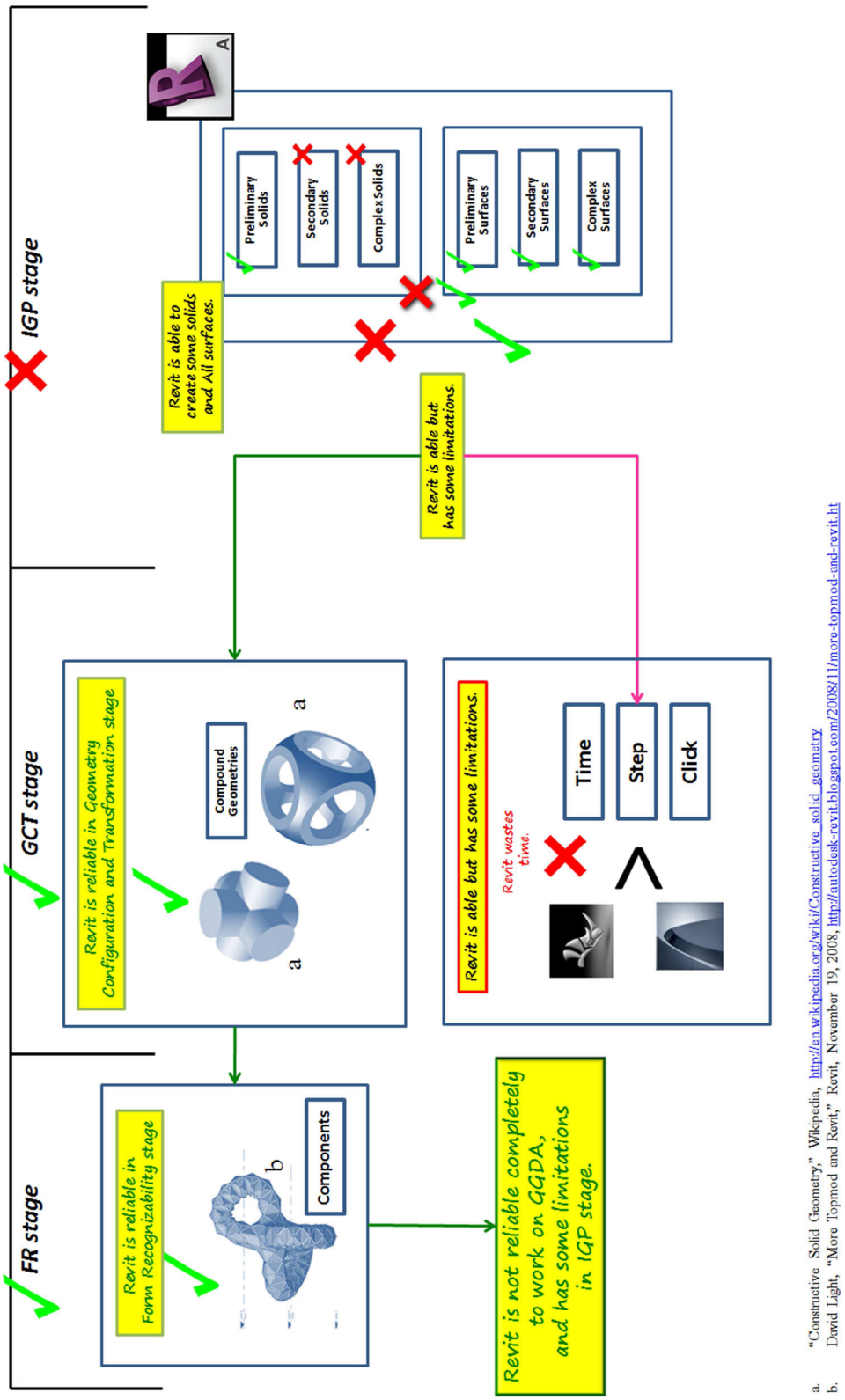
The investigation of Revit Architecture's abilities and limitations in GGDA was based on two methods. In the main method, the researcher explored Revit Architecture in all of GGDA stages in comparing with Rhinoceros, whereas in the confirmation method, five students examined Revit in the first stage of GGDA which is IGP stage.

5.1. The Conclusion of the Main Method

The final conclusion of the thesis can be obtained by applying the results of each method on the hypothesis of the thesis. For the main method, the agreement of results with the hypothesis is demonstrated in the next table:

Hypothesis	**Result**				
Autodesk Revit Architecture is able to create?	Incredible	Great	Good	Poor	NA
Preliminary solids. ✓		20%	75%		
Preliminary surfaces. ✓		33%	67		
Secondary solids. ✗	33%	11%	22%	22%	11%
Secondary surfaces. ✓			100%		
Complex solids. ✗				100%	
Complex surfaces. ✓		100%			
• Revit Architecture didn't create all the geometry categories. • Revit has the ability to create all surface categories. • Revit has limitations in creating secondary and complex solids. • Complex solid and surface categories only included ***one geometry***, whereas secondary solids category included ***nine geometries***.	✗ Autodesk Revit Architecture has the ability of ***78%*** to work on ***Initial Geometry Preparation stage*** in GGDA with limitation in work on solid geometries.				
Autodesk Revit Architecture is able to create all solids in?	✗ Autodesk Revit Architecture has ***limited ability*** to work on ***Initial Geometry Preparation stage*** in GGDA.				
• Shorter time than Rhino. ✗					
• Fewer steps and clicks than Rhino. ✗					
Autodesk Revit Architecture is able to create all surfaces in:					
• Shorter time than Rhino. ✗					
• Fewer steps and clicks than Rhino. ✗					
Autodesk Revit Architecture has the ability to create compound geometries.	✓ Autodesk Revit Architecture is reliable to work on Geometry Configuration & Transformation Stage in GGDA.				
Autodesk Revit Architecture is able to create compound geometries in shorter time than Rhino. ✗	✗ Autodesk Revit Architecture has limited ability to work on Geometry Configuration & Transformation Stage in GGDA.				
Autodesk Revit Architecture has the ability to apply its components on all solids and surfaces.	✓ Autodesk Revit Architecture ***is reliable*** to work on ***Form Recognizability Stage*** in GGDA.				
Autodesk Revit Architecture is able to create apply the components in shorter time than Rhino. ✓	✓ Autodesk Revit Architecture has Great ability to work on Geometry Configuration & Transformation Stage in GGDA.				
Autodesk Revit Architecture 2011 is *NOT* reliable *COMPLETELY* to work with *GGDA*. **It has some *limitations* in IGP stage.**					

Table 24: shows the agreement of main method's results with the hypothesis of the thesis.



a. "Constructive Solid Geometry," Wikipedia, http://en.wikipedia.org/wiki/Constructive_solid_geometry
b. David Light, "More Topmod and Revit," Revit, November 19, 2008, http://autodesk-revit.blogspot.com/2008/11/more-topmod-and-revit.ht

Diagram 18: The applicability of the results with Hypothesis diagram.

According to the results of the main method and the previous hypothesis table and diagram, it can be concluded that Revit cannot be reliable completely to work on GGDA because of some limitations. Although the researcher did not create all the geometries that are listed on page 41, Revit Architecture showed ***78%*** of Good ability in IGP stage in a period of five months. The researcher had to choose one geometry in both of the complex solids and surfaces categories due to time constraints. On other hand, Revit proves Good ability in GCT stage and Great ability in FR stage in consequence of the fact that it is a BIM application.

The limitations that have effects on the reliability of Revit Architecture include the time consumption. Revit Architecture requires long time to achieve the first stage of GGDA. The results of the main method shows that Revit consumed approximately ***24 hours*** to show 78% of Good ability, whereas Rhino required ***four hours*** as maximum to achieve 100% of the experiments. The results illustrate also that the wasted time in Revit Architecture is equal to 2.5 of its productive time. Accordingly, Revit Architecture showed in the main method a limitation in the case of time manner in the first two stages of GGDA which they are IGP and GCT.

The other limitation that contributes to the low reliability of Revit Architecture is the insufficient flexibility and the ambiguity of its interface. The interface of Revit Architecture showed low rate of compability, flexibility, and learnability when compared with Rhinoceros's interface in Table 12[52]and Appendix D. For these low rates, the number of steps and clicks are affected and increased, and more time is consumed. Low

[52] See page 114.

rate of learnability is related to the different format of Revit's interface from the standard format of design software's interfaces. This difference makes it difficult on the user to remember the places of the commands, the tabs and the icons on the interface. This imperfection advances time consumption problem.

The creation process of geometries with pointed ends or parts in Revit Architecture such as pyramid and tetrahedron is difficult to be managed at the beginning and requires long time to be detected. For instance, the creation process of the pyramid in Revit required some calculations to determine the appropriate height of the pyramid to the length of its side. It also required to join four identical pyramids that have two perpendicular surfaces as shown in Figure 74, and required to add a void prism at the bottom of each joined part as a subtraction operation. This process lasted about two hours and a half to be determined.

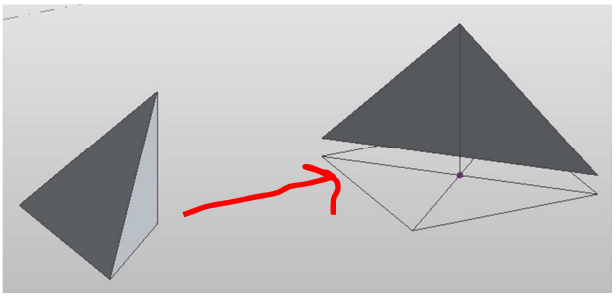


Figure 74: shows the creation process of pyramid geometry in Revit Architecture.

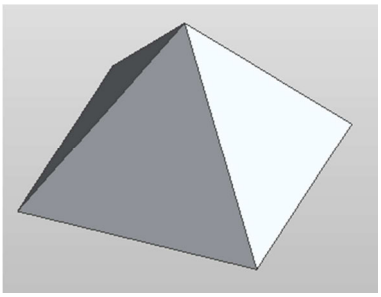


Figure 75: the pyramid in Revit Architecture.

In addition to the previous limitations, there are some technical constraints that have an impact on the flexibility of the work on Revit Architecture. These constraints include the necessity to specify the work plane of drawing steps. For instance, drawing a vertical line

in Revit requires a prior determination of a vertical work plane for this line. This process requires three steps to be achieved. Besides, the levels in Revit that are created by duplicating the first level whether in elevation, 3d, or section view don not appear automatically in Project Browser which make switching between these views is difficult. Therefore, the user should create these levels again in the Project Browser or create them from the beginning.

5.2. The Conclusion of the Confirmation Method

The same process of acquiring the conclusion of the main method was pursued to obtain the conclusion of the confirmation method. In this process, the results were applied on the hypothesis table as follows:

<table>
<tr><td>Hypothesis</td><td colspan="5">Result</td></tr>
<tr><td>Autodesk Revit Architecture is able to create?</td><td>Incredible</td><td>Great</td><td>Good</td><td>Poor</td><td>NA</td></tr>
<tr><td>• Preliminary solids. ✓</td><td></td><td>100%</td><td></td><td></td><td></td></tr>
<tr><td>• Secondary solids. ≈</td><td></td><td></td><td>50%</td><td></td><td>50%</td></tr>
<tr><td>• Complex surfaces.≈</td><td></td><td></td><td>✓50%</td><td></td><td>✓50%</td></tr>
<tr><td>• Students didn't create all the geometries.
• All Students were able to create the preliminary solid "prism".
• Students faced problems in creating the secondary solid and the complex surface.</td><td colspan="5">✗Autodesk Revit Architecture has the ability of 67% to work on <u>Initial Geometry Preparation stage</u> in GGDA with limitations in working on the secondary solid and the complex surface.</td></tr>
<tr><td>Autodesk Revit Architecture is able to create all solids in?</td><td colspan="5" rowspan="5">✗Autodesk Revit Architecture has <u>limited ability</u> to work on <u>Initial Geometry Preparation stage</u> in GGDA in <u>Time manner</u>.

✓Autodesk Revit Architecture has good ability to work on Initial Geometry Preparation stage in GGDA in the least possible number of steps.</td></tr>
<tr><td>• Shorter time than Rhino.✗</td></tr>
<tr><td>• Fewer steps than Rhino.≈</td></tr>
<tr><td>Autodesk Revit Architecture is able to create the surface in:</td></tr>
<tr><td>• Shorter time than Rhino.✗
• Fewer steps than Rhino.✓</td></tr>
<tr><td>Autodesk Revit Architecture has the ability to create compound geometries.</td><td colspan="5">No Experiments.</td></tr>
<tr><td>Autodesk Revit Architecture has the ability to apply its components on all solids and surfaces.</td><td colspan="5">No Experiments.</td></tr>
<tr><td colspan="6">Autodesk Revit Architecture 2011 is NOT reliable COMPLETLY
to work on <u>IGP stage</u>.</td></tr>
</table>

Table 25: shows the applicability of the results of the confirmation method with the hypothesis of the thesis.

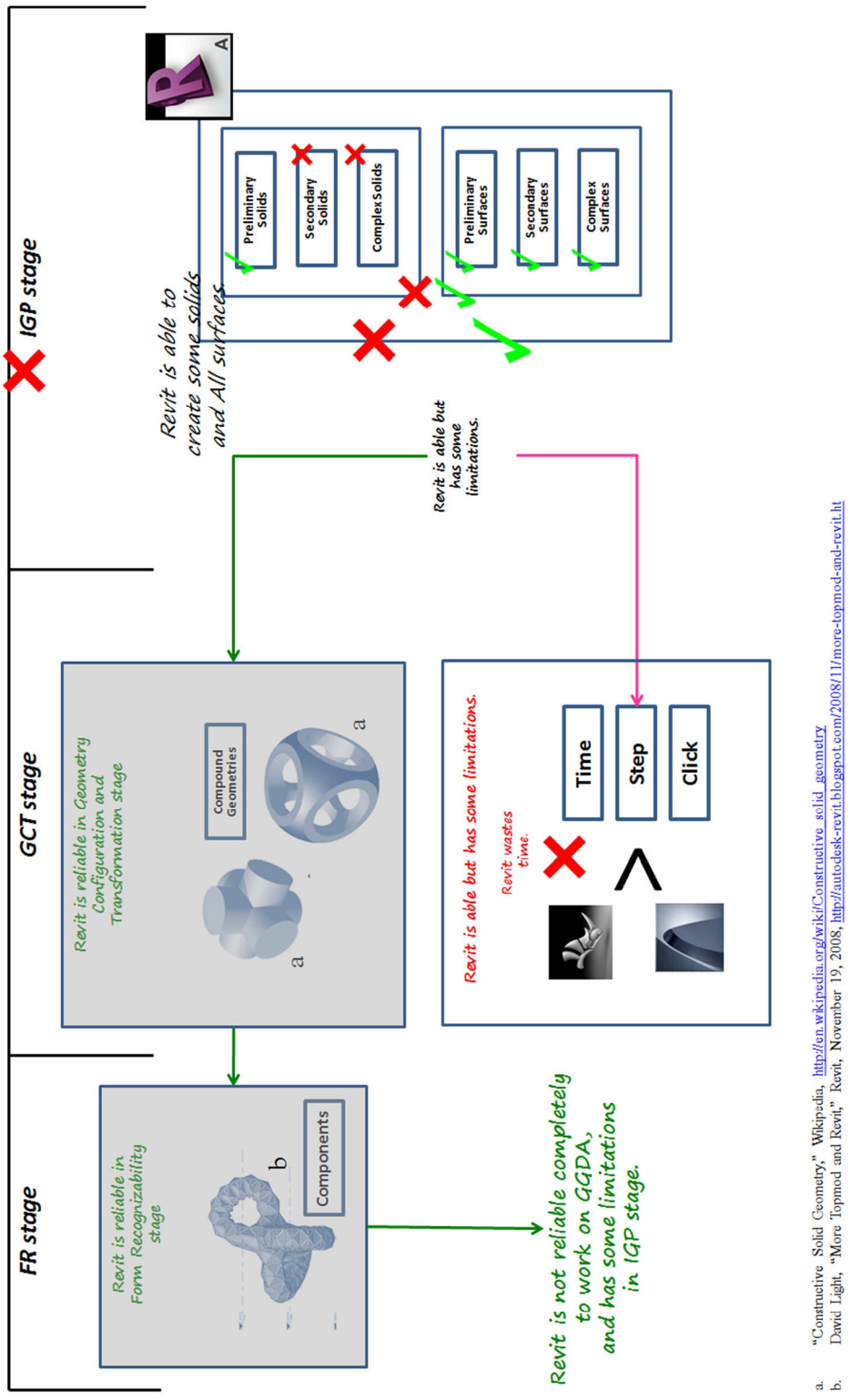


Diagram 19: shows the applicability of the results of the confirmation method with the diagram of the hypothesis.

The results of the confirmation method and the results of the hypothesis table above could not prove the hypothesis of the thesis. Some of the participants in the experiment were not able to create some of the geometries in Revit Architecture especially the complex surface. They justified these results to some limitation in Revit Architecture and limitations in the experiment. Here are lists of the both limitations that the participants mentioned in the post-questionnaire.

The limitations of Revit Architecture by the participants:

- The ambiguity of Revit's interface makes it difficult for the user to realize the places of the commands and icons which wastes a lot of time.
- Revit Architecture offers limited options for the user if compared with the options that Rhinoceros provides.
- Revit Architecture has good ability in creating solids, but it has limitations in creating complex surfaces.
- Massing the concept in Revit is more difficult and complicated than create them in other 3D softwares.
- The only good feature of creating the mass in Revit Architecture is the deformation process This process provide the user with the ability to drag and move the corner points and edges of the form.

The limitations of the experiment by the participants:

- The geometries in the experiments were complicated and made the participants feel frustrated, especially the mobius strip.
- It was difficult for the participants to use the Mac computers during the experiment, because they are used to work on Pc computers.

Pursuant to the confirmation method's results, Revit Architecture cannot be considered an entire reliable to work on IGP stage of GGDA. Revit showed in this experiment 60 % of Great and Good abilities, while other 40% of the result was neutral. On other hand, Revit demonstrated a Good ability to achieve the successful experiments with fewer steps than Rhinoceros. At the same time, it displayed a limitation in time manner. The results shows that the wasted time in Revit is twice the productive time. However, this result is considered good if compared with the proportion 3.6:1 of the waste time to the productive time in Rhino. It cannot again be concluded that Revit has the full ability to work on IGP stage because of the limited number of geometries that were created by the students in this method as a result of the short time of the research and the limited time of the experiment. Subsequently, Revit Architecture cannot be dependent entirely to work on the first stage of GGDA due to a number of failed experiments in creating some of the selected geometries.

5.3. The Overall Conclusion

It can be concluded from the results of the main method and the results of the confirmation method that Revit Architecture has some limitations in working on the first stage of GGDA, and the users of GGDA cannot depend on it entirely in the conceptual design phase. However, it showed Good ability to work on that stage with approximate 73%, and this ratio is considered a good result in comparing with other BIM application such as ArchiCAD. This fact provides an indication of the development of Revit Architecture application that obtained recently. Revit Architecture proved that it combines between the abilities of NURBS modeling softwares and BIM applications in the same time.

It is important to admit the fact that there is no software with the full specifications and options, but it is also substantial to affirm that Revit Architecture is approximate to be full and absolute software because it merges between some features of 3D modeling which they are: solid modeling, surface modeling, and NURBS modeling, and between the features of building information modeling like: building components, spatial relationship, quantities and properties. It can be that integrated application if its limitations has been adjusted and removed.

Design Process	Application	Rhinoceros 	Autodesk Revit Architecture 	ArchiCAD 
Schematic Phase	**GGDA stages**	✗	✓	✓
Modeling the site		✓	✓	✓
Site analysis		✗	✓	✓
Conceptual Design Phase	**Initial Geometry Preparation IGP**	✓Excellent in creating solids and surfaces.	✗ Good in creating solids and surfaces with some limitations	✗ Good in creating solids but only for creating other components.
	Configuration & Transformation GCT	✓Excellent in creating compound geometries.	✓Good in creating compound geometries.	
	Final Form Recognizability FFR	✗It doesn't have components.	✓Great in applying components on the created forms	
Architectural Drawings		✗	✓	✓
Detailed Drawings		✗	✓	✓

Table 26: illustrates a comparison between Rhinoceros, Revit, and ArchiCAD in the phases of design process.

In the previous table, we can notice that Revit Architecture has most of the features of both 3D modeling and Building Information Modeling. It has only some limitations in working on IGP that make it not fully compatible with GGDA. The limitations include:

Limitations	Explanation	Effect	Recommendation
Confused Interface	It doesn't follow the standard format.	• Can't remember the places of commands and panels. • The user feel distract and confused. • Increase time consuming. • Increase the number of clicks.	• The organization of the tabs should be more logic. • Using labels that are standard and understandable. • Adding customization option to make the interface more flexible. • Switching between the opened files should be easier.
Limited ability of NURBS and editing operations.	The user can only move the corner points or edges, it is difficult to add point on the faces and drag them.	Can't create geometries with pointed end or parts easily as the pyramid or the tetrahedron.	Make it possible to divide to add control points on the faces and make it easier to drag them to different directions.
Work space is limited to only one axis.	The user only can work on one axis for each step. It is necessary in Revit to change the work plane if the user decided to work on new axis.	• Time consuming. • The user feel distract and confused. • Increase the number of steps and clicks.	The work plane changes automatically as in other 3D modeling softwares.
The levels should be created in both Project Browser and the elevations or other views.		• Time consuming. • The user feel distract and confused. • Increase the number of steps and clicks.	The levels that are created whether in the Project Browser or views are added automatically to all views and vice versa.
The constrained activity for some commands.	• Scale command works on specific objects. • Snap, Move, Copy and rotate commands are adhered to the specified work plane. • Limited options of drawing the polygons and ellipse shapes.	• The user feel distract and confused. • Inflexibility of work. • Limit the Intellectual activity of the user.	Extend the activities of the commands and loose their boundaries.
New names and notion of Boolean operations.	Boolean operations in Revit Architecture are presented by different name. They are presented by Join, Cut commands in Geometry panel. And also presented in Solid and Void options.	• The user feel distract and confused. • Increase time consuming to understand the new notion and commands. • missing the operation of intersection which is important. • The problem of void form that it can't be deleted, it stays connected with the geometry and if the user wanted to add another form to it appears again, and can't be hided.	Using the standard name and the notion of Boolean operations make it easier for the user to find them and work on them easily because of his/her previous background about them in other 3D modeling softwares.

Table 27: shows the limitations of Revit Architecture, their effects, and possible solutions for them.

It is worth mentioning that the conclusion of this study is dependent on accurate results and well organized analysis and hypothesis, but there were some limitations that might affected the findings. The limited time of the research is one of these limitations. Seven months to work on the thesis seems enough, but the late decision to have the confirmation method's experiment affected the timetable of the research. Accordingly, the researcher focused on the first stage of GGDA in the confirmation method and chose to create some of the geometries on page 41 in order to regulate the time of the experiment to be compatible with the timetable of the research. Moreover, the preparation process for the experiment of the confirmation method lasted about two months. The researcher faced difficulties to find a suitable computer lab for the experiment and difficulties to have volunteers for the experiment. This is in addition to the administrative obstacles that the researcher confronted in terms of the delay of obtaining the permission to work on the experiment, the delay of getting the permission to use the computer lab, and the complicated procedures to install the softwares to the computers. These constraints contributed to have the experiments in a late date. The experiments were carried out on the 25th and 26th of February in 2011, a month before the deadline of the final research submission, which make the opportunity to have an additional experiment is an impossible idea.

Furthermore, the small sample of participants that took part in the both methods affected the analysis process. The few number of participants led the researcher to depend on the descriptive statistics to analyze the data instead of using more advanced analysis tests. Ultimately, the psychological and physical aspects of the most participants in the both

methods were clearly stressful and tired which have an impact on the results of the experiments. These conditions are considered in the analysis process as one of the IndVs.

Even though this research may not cover all the aspects and may not comprehend all the issues, this small piece of a study opens more comprehensive future studies about GGDA and about other different generative design approaches. It is recommended for the future studies about the compability of BIM applications with different design approaches to have no limitations in the time of the researches and to have at least two experiments to confirm the results. These experiments have participates with equal experiences. For instance, it is advisable for any extended future study to work on a complemented experiment with participants that have the same experience in working on Revit and Rhino. The selection of the participants is important to achieve the goal of the experiments. It is also recommended for the future studies to examine Revit Architecture with more complex geometries and forms. And explore the compability of this software with other generative design approaches.

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Appendix A

The Comparison between BIM applications

Application			Revit	Bentley	ArchiCAD	Digital Project	AutoCAD-based Applications	Nemetschek's AllPlan	DProfiler
Year introduced			2002[53]	2004[53]	1984[61]				2006[60]
Scripting Language					GDL				
Using			Architecture/ Structure	Architecture/ Engineering/ Construction[53]	AEC (Architecture Engineering Construction)	Architecture/ Structure/ MEP		Architecture/Engineering/ Services/ Site design[59]	Architecture[60]/ Construction/ Economy
Products			Revit Architecture/ Revit Structure/ Revit MEP[53]	Bentley Architecture/ Structural/ Building Mechanical Systems/ Building Electrical systems/ Facilities/ PowerCivil/ Generative Component[53]				Allplan BIM Architecture/ Allplan Engineering/ Allplan Building Services/ Allplan BCM/ Allplan IBD [59]	
Features	Interface		*[53]	*[53]	*[53]	*[58]	*[53]	*[59]	*[60]
	2D Drawing	line weights	*		*				
		Layout	*		*	* [58]		* [59]	
	3D Modeling & Editing	Components	*	*[55]	*GDL[53]	*[58]	*[53]	* [59]	*[60]
		Line							*[60]
		Curve							*[60]
		Surface	*	*[53]	* Maxon[53]	*[53+ 58]	*[53]	* [59]	
		Solid	*	*[55]		* [58]	*[53]	* [59]	
		NURBS		*[53]		* [58]		*[68]	
		Bezier		*[53]					
		Meshes							
	Animation			*[55]	*			* Cinema 4D [59]	
	Rendering/ Plug-ins		AccuRender	Luxology[55]	Artlantis 2.0			*Cinema 4D [59]	
	Views			*[55]				* [59]	
	Prototyping			* STL file [56]		* STL file [53+58]			* STL[60]
	Scalability		*	*[53+ 55]	*[53]	*[53]	*[53]		
	Interoperability	Import	DXF/ DWG/ PDF/ DWF/ DGN /ODBC/ gbXML/BMP/JPG/TGA/TIF/Skp/ SAT[53]	Skp/ 3dm	3Ds/ ACIS/ SAT/ BMP/ DWG/ DWF/ DXF/ GIF/ JPG…	dwg/ dxf/ stp/ wrl/ stl/ hsf/ sdnf/ 3dxml/ igs/ hcg/ ifc/ sat [58]		DWG/PDF/DX[59]/ DWG[58]	DWG/ DXF/ Excel[60]
		Export	JPG/ PNG/ AVI[53]	3D PDF/ VRML/ QuickVision/panoramas[56]	AVI/ BMP/ DWF/ DWG/ DXF/ Piransi/ GIF/ JPG/ PDF/ Collada	dwg/ dxf/ stp/ wrl/ stl/ hsf/ sdnf/ 3dxml/ igs/ hcg/ ifc [58]		AVI[56]/PDF [59]	PDF/ HTML/ DOC/ XLS/ CEF/ IGES/ DWG/ DXF[60]
		Import & Export features	Support (BIM/ IFC[53]/ DEF).	- support (DGN/ DWG/ DXF/ PDF/ STEP/IGES/ IFC)[53]	- Support (BIM/ IFC/ DEF). - BuildITC4 → Collada File (VR).	CIS/2 /SDNF/ STEP AP203+ AP214/ DWG/ DXF/ VRML/ HOOPS/ SAT/ 3DXML/ IGES/ HCG/ IFC[53]	DGN/ DWG/ DWF/ DXF/ IFC[53]	PDF/ IFC[59]	IFC[60]
	Extensibility					API[BIM]/ Visual Basic programs/ VBScript[53]/ JScript [58]	AutoLISP/ Visual Basic/ VB Script/ ARX(C++)[53]		
	Collaboration		*	*BentleyProjectWise®(Collaboration server)[56]	*(Server-based Collaboration)[3]	* [58]		* [59]	

	Extension				.CATPart/ .CATProduct[58]			
	Environmental analysis	gbXML/ Sunpath[53+54]						* eQuest[60]
	Object Library	*[53]	*	*[53]	*[6]	*[53]	*[59]	*[60]
	System	In-memory[53]	File-based[53]	In-memory[53]		In-memory [53]	Sub-folders and files[59]	
Design Process	**Sketch/ drawing**							
	Physical Model							
	Site Planning	*		*				*AutoPark tool/ Google Earth[60]
	Conceptual Mass	*	*[55]				*[59]	*[60]
	Space Planning		*[55]	*			*[59]	*[60]
	Environmental analysis	* (IES)		* (IES)			*[59]	*eQuest[60]
	Architectural Drawings	*	*[55]	*			*[59]	
	Structural Drawings	*	*[56]	*			*[59]	
	Specifications & Quantities		*[56]	*			*[59]	*[60]
	Schedule	*	*56	*			*	*[60]
	Budget		*[56]	*			*[59]	* RSMeans60
Cost		$5,495[53]+[54]	Non-Microstation users : $6,290 [55] Microstation users: $1,495 [55]	$4,250 Free educational version[57]	Professional License: $ Academic License: $ 150[58]		$ 5995 [59]	*Network License: $ 7500 + $1500 annual fee *Non subscription version: $ 5000[8]
Operating systems		Windows	Windows [56]	Windows/ Mac[53]	Windows		Windows/ Mac [59]	
Company		Autodesk [53]	Bentely	Graphisoft [53]	Gehry Technologies [53+ 58]		Nemetschek [59]	Beck Technologies[60]
Latest Version		Revit 2011	Bentley Architecture V8i	ArchiCAD 14	Digital Project V1, R4[58]		Allplan BIM 2009[62]	
Advantages		* Automated updated views.[55] *New tools in conceptual massing. *Great enhancement in interface tools and menus. * Good documentation abilities. *Parametric Modeling. *Improvements in display options. *New material library. * Speed up	* Automated updated views. *Sophisticated abilities in creating conceptual masses which is considered similar to Sketchup abilities. *Active Flexible views. *Fast performance. *Wide-ranging interoperability. *Good space planning abilities. *Great	*automated and manual updated views. *More developed collaboration abilities.[57]	* Full parametric definition. * Creating complex and parametric geometry.[53] * Part file storage method. * Producing architectural, structure, MEP and manufacturing documents.[58]	*Quick adoption by AutoCAD users/ Easy learn[53]	*Create complex surfaces and organic shapes.[59] * Well-organized tool and interface.[59] *All discipliners meet at the same application in opposite of other BIM applications.[59]	*Useful for feasibility study.[53] *Quick economic assessment[53] *Great in cost estimation. *Sketchup Massing capabilities. *Detailed tutorials. *Quick and easy to use. *Exporting to another BIM by IFC.[60]

[53] Chuck Eastman et al., *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*, (Hoboken, N.J.: Wiley, 2008).
[54] Lachmi Khemlani, "AECbytes Product Review: Revit Architecture 2011," AECbytes (August 26, 2010), http://www.aecbytes.com/review/2010/RevitArch2011.html
[55] Lachmi Khemlani, "AECbytes Product Review: Bentley Architecture V8i," *AECbytes* (November 19, 2009), http://www.aecbytes.com/review/2009/BentleyArchV8i.html

	operations.[53+ 54]	Rendering. *Energy, Structural, and construction analysis. *Generative Components for parametric design.[55] *Parametric Components.[56]					
Disadvantages	*Doesn't Support complex curved surfaces.[53] *Lacks in conceptual modeling abilities in comparing with other BIM applications. * Complicated conceptual massing interface. *Minor enhancements in dealing with large projects and managing the workflow. *Poor collaboration skills.[53+54]	*Difficult to learn.[53] *Complex software interface and commands. *Poor Quality documentations.[55]	*Not widely cooperating with other applications. *no differentiate between Room/Spaces. *Limited conceptual mass abilities.[57]	* Complex user Interface.[53] * High initial cost.[53] *Object library is limited.58	Not Parametric Modeling/ limited interface/ Slow because of In memory[53]	* Multi files for different views.[59] *Open new application for each new project.[59] *Lack of associativity.[59] *Poor quality documents.[59] * Difficult to learn. *No tutorial.[59]	*3D modeling constrained. *Poor room layout. *No model integrity checks. *Complicated cost interface. *No wall, window...etc. tools. *Difficult for space planning.[60+61+62]

[56] Bentley," A comprehensive building information modeling (BIM) solution for architectural design and documentation," (2004), www.bentley.com

[57] Lachmi Khemlani, " AECbytes Product Review: ArchiCAD 13." *AECbytes* (September 30, 2009), http://www.aecbytes.com/review/2009/ArchiCAD13.html

[58] Digital Building Lab, "Digital Project, *"Georgia Institute of Technology*, http://bim.arch.gatech.edu/content_view.asp?id=526

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[61]Edward Goldberg, "Software strategy: BIM comparison: how does BIM software stack up with the 3D model concept?" *BNET: CBS Business Network*, (January, 2005), http://findarticles.com/p/articles/mi_m0BLL/is_1_22/ai_n11836215

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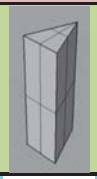
Appendix B

Main Method collected Data

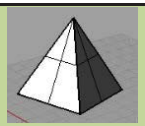
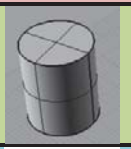
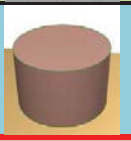
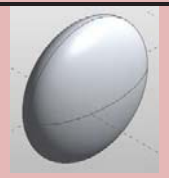
Solids:

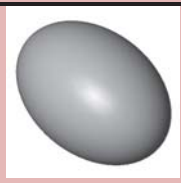
a. Preliminary solids:

Comparison Factor / *Software*	*Date*	*Time* 1st Time	*Time* 2nd Time	*Clicks*	*Steps*	*Difficulties*	*Notes*	*Comparison Factor* / *Geometries*
Revit Architecture	26.10.2010		00:00:53 ✔	37	1. Open Revit Architecture. 2. Choose New Conceptual Mass in families' files. 3. Choose Mass in the dialog. 4. Select Manage tab. 5. Click on Project Units icon. 6. Modify the units depending on what you want. 7. Activate Level 1. 8. Click on Home tab. 9. Select circle in Draw panel. 10. Draw a circle on the view. 11. Activate 3D view. 12. Select the circle. 13. Click on Create Form>Solid Form. 14. Choose Sphere option that Revit offers.		MM	***Sphere*** 
Rhino	09.11.2010		00:00:43 ✔	23	*Open Rhinoceros. *Choose Meter/inch file. *Activate Perspective view. *Click on Sphere: Center, Radius icon. *Select the center of the sphere in the view. *Determine the radius manually or by writing it in command bar.		Default Parametric Sphere	
ArchiCAD	09.11.2010	00:02:19 ✔			* Click on Object in Toolbox. *Click on Object icon in the tool bar of Object. *In Folder list select: ArchiCAD Library 14> Special construction> Basic shapes. * Select Sphere in the list. * Change parameters. *Click OK. * Click anywhere in the view.		Default Parametric Sphere	
Revit Architecture			00:13:00 ✘ 00:03:55 ✔		10 *Go to elevation *Select Model line. *Draw a Triangular *Go to 3D view *Set the work plane on Tringular. *Select Solid Revolve command in Form bar. *Select boundary lines *Select axis lines * Click ✔ sign	* 3D Snapping in Generic Model file. *cone can't be created in Mass Model, because has no Revolve command.	GM GM	***Cone*** 
	04.12.2010 18.02.2011	00:01:30 ✔	00:02:22 ✔	47 136	1. Open Revit Architecture. 2. Choose New Conceptual Mass in families' files. 3. Choose Mass in the dialog. 4. Select Manage tab. 5. Click on Project Units icon. 6. Activate Elevation view. 7. Click on Home tab. 8. Select Line icon in Draw panel. 9. Draw a triangular. 10. Select the vertical side of the triangular. 11. Press Delete.			

					12. Select line icon. 13. Draw a line that on the same extent of the deleted line but not connecting the endpoints of the other lines. 14. Activate 3D view. 15. Select all lines. 16. Click on Create form> solid Form. 17. Choose Cone option that Revit offers.			
Rhino	09.11.2010		00:00:10 ✔	15	*Open Rhinoceros. *Choose Meter/inch file. *Activate Perspective view. *Click on Cone icon. *Specify the center of cone's base. *Specify the radius. *Specify the height.		*Default Parametric Cone.	
ArchiCAD	09.11.2010	00:00:49					*Default Parametric Cone. *Same steps as Sphere & Prism.	
Revit Architecture	26.10.2010	00:01:16 ✔			1. Open Revit Architecture. 2. Choose New Conceptual Mass in families' files. 3. Choose Mass in the dialog. 4. Select Manage tab. 5. Click on Project Units icon. 6. Modify the units depending on what you want. 7. Activate Level 1. 8. Click on Home tab. 9. Select Circumscribed Polygon icon in Draw panel. 10. Specify 3 in sides bar. 11. Draw a triangular in Level view. 12. Activate 3d view. 13. Select the triangular. 14. Click on create Form> Solid Form.		MM	***Prism***
	11.11.2010		00:00:42 ✔	34			MM	
Rhino	09.11.2010	00:00:20	00:00:19 ✔	28	*Open Rhinoceros. *Choose Meter/inch file. *Activate Top view. *Click on Polyline icon. *Draw any closed shape. *Activate Perspective view. *Select the shape. *Click on Extrude Planar Closed Curve. *Specify the height of the prism.			
ArchiCAD	09.11.2010	00:01:12			* Click on Object in Toolbox. *Click on Object icon in the tool bar of Object. *In Folder list select: ArchiCAD Library 14> Special construction> Basic shapes. * Select Prism in the list. * Change parameters. *Click OK. * Click anywhere in the view.		Default Parametric Sphere	
Revit Architecture	27.9.2010	00:35:00 ✕				* No 3D snapping, make it difficult to snap vertical line to the horizontal ones.	GM	***Pyramid***
	27.9.2010	01:17:00 ✔			26 * Draw Rectangular *Draw lines divide the Rec to 4 rectangulars. * Set vertical work plane.	* Only could create facet Pyramid ...not volume one.	MM - Facet Pyramid - 3D snapping option	

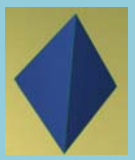
					*Draw vertical line in Rec center. * Connect the edge points of Rec to the upper endpoint of vertical line with model lines. *Select each 3 connected 3 lines to create a surface for the Pyramid. *After selecting create Form and choose the surface option. *Redo that step for each face. *select the Rec and create form too, it will not give surface option, so create a box. * Select the upper or under surface of the box and copy it. * Delete the box. *Move the Rec surface and connect it to other surfaces to create the Pyramid.			
	04.02.2011 18.02.2011	00:40:44 ✔	00:10:46 ✔	682	*Open Revit Architecture. *Choose New Conceptual Mass in families' files. *Choose Mass in the dialog. *Activate Lvel1 view. *Select Manage tab. *Click on Project Units icon. * Modify the units depending on what you want. *Activate Level1. *Select Home tab. *Click on Rectangular icon in Draw panel. *Draw a rectangular 10mX10m for example. *Select Line icon. *Draw lines that present the diagonals of the rectangular. *Click on Measure icon in Measure panel. *Measure the distance between the half of diagonal. *write it down. *Try to calculate the height of the pyramid using Pythagoras theorem. *activate any elevation view. *Select Line icon. *Draw the rectangular that present Pythagoras theorem. *Activate 3D view. *Select Line icon. *Draw a line that connect the midpoints of the rectangular, *Click on Reference Plane in Draw panel. *Select the later line to create vertical work plane. *click on Show in Work Plane panel. *Select Line icon. *Draw a vertical line that start from the center of the rectangular with the distance of pyramid's height. *Select Line icon. *Check 3D Snapping. *Draw lines connect the peak of vertical line with the corner points of the rectangular. *Select Copy icon in Modify panel. *The rectangular is divided to four similar triangulars. *Select one of the triangulars with the vertical line and diagonal lines. *Select copy icon. *drag a copy. *Select the triangular again. *Click on Create form>Solid form. *Extrude the upper surface of the prism to reach the peak of the pyramid's height + 1 meter. *Select the side of Prism that measure 10 meter (The longest one). *Click on Set icon in Work Plane panel to make it as work plane. *Select Line icon. *Draw a line that measure 1 meter vertical on a vertical edge of the previous side. *Select the upper horizontal edge of that side, *Drag it down to reach the end point of the vertical line that we draw lately. *Select the side that remains vertical below. *Click on Set in Work Plane panel to make it the work plane. *click on Rectangular icon in Draw panel. *Draw a rectangular over the remaining side and applicable to it. *Select that rectangular. *click on Create Form>Void Form. *Extend the resulted form. *Select the previous rectangular. *enter Delete. *Activate Level1 view. *Select all the resulted form. *Click on Rotate icon in Modify panel. *Drag the center of rotation to be on the peak of the pyramid. *Check Copy. *Rotate the form 90^0. *Do the rotation process again to create other two forms which will result a pyramid at the end.			

Rhino	09.11.2010		00:00:11 ✔	15	*Open Rhinoceros. *Choose Meter/inch file. *Activate Perspective view. *Click on Pyramid icon in toolbar. *Specify the number of pyramid's sides to 4 sides in Command bar. *Press Enter. *Specify the center of Pyramid/s base. *specify the circumscribe of the base. *Specify the height.			
ArchiCAD	09.11.2010	00:01:00			* Click on Object in Toolbox. *Click on Object icon in the tool bar of Object. *In Folder list select: ArchiCAD Library 14> Special construction> Basic shapes. * Select Pyramid in the list. * Change parameters. *Click OK. * Click anywhere in the view.		*Default Parametric Cone.	
Revit Architecture	26.10.2010		0:00:24 ✔	21	1. Open Revit Architecture. 2. Choose New Conceptual Mass in families' files. 3. Choose Mass in the dialog. 4. Select Manage tab. 5. Click on Project Units icon. 6. Modify the units depending on what you want. 7. Activate Level 1. 8. Click on Home tab. 9. Select circle in Draw panel. 10. Draw a circle on the view. 11. Activate 3D view. 12. Select the circle. 13. Click on Create Form>Solid Form. 14. Choose Cylinder option that Revit offers.		MM	***Cylinder*** 
Rhino	09.11.2010		00:00:17 ✔	11	*Open Rhinoceros. *Choose Meter/inch file. *Activate Perspective view. *Click on cylinder icon in toolbar. *Specify the center of the cylinder in the view. *Specify the radius. *Specify the height.			
ArchiCAD	09.11.2010		00:00:36				*Default Parametric Cylinder. *Same steps as Sphere & Prism.	
Revit Architecture	19.9.2010	00:17:00 ✕						***Ellipsoid***
	15.11.2010	00:01:10✕						
	15.11.2010	00:07:19 ✔		253	*Open Revit Architecture. *Choose New Conceptual Mass in families' files. *Choose Mass in the dialog. *Activate Lvel1 view. *Select Manage tab. *Click on Project Units icon. * Modify the units depending on what you want. *Select Home tab. *Select Circle icon in Draw panel. *Select the center of the circle on the view. *Specify the radius of the circle. *Activate 3D view.		MM	

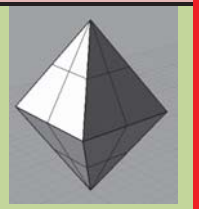
					*Select the circle. *Click on Create Form > Solid Form...in Form panel. *Select Sphere option that Revit offers. *Select the upper part of the sphere. *Click on Edit Profile icon in Mode panel. *Activate Level1 view. *Select the arc profile. *Select Partial Ellipse from Draw panel. *Draw an ellipse as the profile of the sphere. *Delete the original profile. *Click on Finish Edit Mode icon in Mode panel.			
	15.11.2010	00:02:54 ✔	00:01:09 ✔	118 43	*Open Revit Architecture. *Choose New in families' files. *Choose Generic Model in the dialog. *Activate Ref, Level view. *Select Manage tab. *Click on Project Units icon. * Modify the units depending on what you want. *Select Home tab. *Click on Revolve icon in Forms panel. *Select Partial Ellipse in Draw panel to create Boundary Line. *Draw partial ellipse. *Select Line icon. *Draw a line connects the end points of the ellipse. *Select Line icon to draw Axis Line. *Draw a line over the previous line. *click on finish Edit Mode icon to finish Revolve operation. *Open New Conceptual Mass file. *Click on Manage tab. *Select Project Unit icon in Setting panel. *Modify the units according to Generic Model file. * Click on Load into Project icon to load the geometry to Mass file. *Check the mass file name. *Click OK. * Activate Mass. File. *Select the generic file from the Project Browser. *Drag the file to the view and place it. *Click on Load into Project icon. *Select the project. File. *Activate Project. File. *Select the mass file from the Project Browser. *Drag it to the view. *Select Place on Work Plane icon in Placement panel.	*The problem of Generic Model that it should be loaded to Mass. File then to Project. File to work on it. If it load directly to Project. File then it can be considered there as Generic model family not as a Mass. Therefore, Floors can't be added to the geometry.	GM	
	15.11.2010	00:03:29 ✘						
	15.11.2010 18.02.2011	00:00:32 ✔	00:01:35 ✔	22 112	*Open Revit Architecture. *Choose New Conceptual Mass in families' files. *Choose Mass in the dialog. *Activate Lvel1 view. *Select Manage tab. *Click on Project Units icon. * Modify the units depending on what you want. *Select Home tab. *Select Partial ellipse in Draw panel. *Draw partial ellipse in Level 1 view. *Select Line in Draw panel. *Draw a line that can be the axis for the arc. *Select the line and the arch. *Click on Create Form in From panel. *Click on Solid Form icon.		MM	
Rhino	09.11.2010		00:00:13 ✔	11	*Open Rhinoceros. *Choose Meter/inch file. *Activate Perspective view. *Click on Ellipsoid; From Center. *Specify the center point of the ellipsoid. *Specify the first radius of the first ellipse. *Specify the second radius of the first ellipse. *Specify the radius of the second ellipse.			

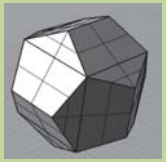
ArchiCAD	09.11.2010	00:00:49			* Click on Object in Toolbox. *Click on Object icon in the tool bar of Object. *In Folder list select: ArchiCAD Library 14> Special construction> Basic shapes. * Select Ellipsoid in the list. * Change parameters. *Click OK. * Click anywhere in the view.		*Default Parametric Part of Ellipsoid.	
Revit Architecture	06.02.2011 18.02.2011	00:02:09 ✔	00:01:09 ✔	114 120	*Open Revit Architecture. *Choose New Conceptual Mass in families' files. *Choose Mass in the dialog. *Select Manage tab. *Click on Project Units icon. *Modify the units depending on what you want. *Click on Home tab. * Activate Lvel1 view. *Click on Reference in Draw panel. *Select Circle icon in Draw panel. *Draw a circle on Level 1 view. *Activate 3D view. *Select Reference again. *click on Point Element in Draw panel. *Specify a point on the circle. *Select the point; a work plane will appear on the point. *Select that work plane. *Click on Set in Work Plane panel. *Click on Show icon in Work Plane panel. *Click on Model icon in Draw panel. *Select Circle icon. *Draw a circle on the work plane which its center is the point element. *Select the both circles in the view. *Click on Create Form>Solid Form.			***Torus*** 
Rhino	09.11.2010		00:00:06 ✔	10	*Open Rhinoceros. *Choose Meter/inch file. *Activate Perspective view. *Click on Torus icon. *Specify the center of the torus. *Specify the radius of the torus. *Specify the second radius of the torus.			
Revit Architecture	28.10.2010	00:11:04 ✕				*Prism Deformation and NURBS operations.	MM	***Tetrahedron*** 
		00:20:37 ✔	00:11:25 ✔			*That is tetrahedron with surfaces doesn't work to create floor plans inside it.	MM Surface Tetrahedron	
	02.11.2010	00:36:54 ✕				*Try to create Tetrahedron with subtracting 3 triangular prism of main triangular prism. *You have to set Work plane for each step which has difficulties to set it.	MM	
	02.11.2010	00:44:56 ✕				*Try to subtract 3 pyramids from triangular prism.	MM	
	02.11.2010	00:08:26 ✕				*Try to create Tetra using lines and create form.	MM	
	02.11.2010	00:30:03 ✕				*Try to use Forms operation (Revolve).	GM	
	02.11.2010	00:29:54 ✕				*Revolve profile around triangular prism.	MM	
	03.11.2010	00:20:34 ✕				*subtract Prism again.	MM	
	03.11.2010	00:05:20 ✕				*Use Add Edge option and NURBS operation.	MM	

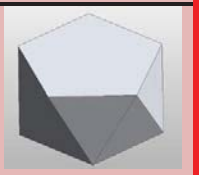
	03.11.2010	00:15:38 ✔		843	*Open Revit Architecture. *Choose New Conceptual Mass in families' files. *Choose Mass in the dialog. *Select Manage tab. *Click on Project Units icon. *Modify the units depending on what you want. *Click on Home tab. * Activate Lvel1 view. *Select Line icon in Draw panel. *Draw Isosceles Triangular with 30 meter side 'length for example. *Select Line icon again. Draw lines that divide to three small identical triangulars. *Select the lines that create one of these three triangulars. *Select Copy icon in modify panel. *Drag a copy. *Activate 3D view. *Select the triangular. *click on Create Form> Solid Form. *Extrude the prism to the height of the tetrahedron + 1 meter. *Select the largest side of the prism. *Select Set in Work Plane panel. *click Show in work Plane panel. *Select Line icon. *draw a line on the edge of the largest face that equal to 1 meter. *Draw other line that connects the previous line with the other side of the face. *Select the upper side of that face. *Drag it with the arrow towards the horizontal line that you draw lately. *Select the remained part of the face that is not slope. *Select Set in Work plane panel. *Select Rectangular icon in Draw panel. *Draw a rectangular that bounder the remained face. *Select that rectangular. *click on create Form> Void Form. *Click outside of the geometry to see the resulted geometry. *Activate Level 1 view. *Select the entire geometry with void part. *Select Rotate icon. *Move the rotation center towards the inner edge of the pyramid. *check Copy box in upper bar. *Rotate one copy. *Repeat the steps... to create anther copy. *Activate 3D view. *Click on Join> Join Geometry. *Select the three pyramids to joint them.	*Dividing the tetrahedron to three connected pyramids. *I wasted a lot of time in repeating the same steps in creating each geometry instead of creating one and copy it to other two copies and connect them.	MM	
Rhino	09.11.2010	00:06:59 ✔					*Different way of creating > long method.	
	06.12.2010	00:02:22 ✔		135	*Open Rhinoceros. *Choose Meter/inch file. *Select Line icon. *Activate Top view. *Select Line icon in toolbar. *Draw a line with 30 meter length. *Calculate the height of tetrahedron with 30 meter side. *Select Line icon again. *Draw a line with the height of tetrahedron's height that is perpendicular to the previous line and starts from its midpoint. *Draw the other sides of the triangular. *Select Line icon again. *Draw lines that connect between the corner point of the triangular with the midpoint of the opposite site of that point. *Click Distance icon. *Calculate the distance between the intersection of the previous lines and one of comer points of the triangular. *Activate Perspective view. *Click on Pyramid icon. *Specify the number of pyramid's sides to 3. *Specify the corner point of the pyramid to the previous calculated distance. *Specify the height of the pyramid.		*Default Parametric	

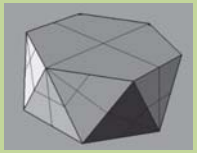
ArchiCAD	15.11.2010	00:01:12			* Click on Object in Toolbox. *Click on Object icon in the tool bar of Object. *In Folder list select: ArchiCAD Library 14> Special construction> Basic shapes. * Select Pyramid in the list. * Change parameters. *Click OK. * Click anywhere in the view.		*Default Parametric Part of Pyramid.	

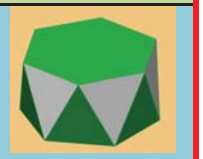
b. Secondary Solids:

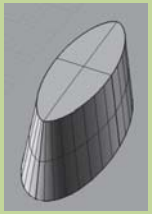
Comparison Factor / *Software*	*Date*	*Time*		*Clicks*	*Steps*	*Difficulties*	*Notes*	*Comparison Factor* / *Geometries*
		1st Time	*2nd Time*					
Revit Architecture	04.02.2011	00:40:44 Create two pyramids. 00:42:19 ✕ Create octahedron by connecting the two pyramids		**1640** ---				***Octahedron***
Rhino	16.11.2010	00:09:24 ✔		**362**	*Open Rhinoceros. *Choose Meter/inch file. *Select Line icon. *Activate Top view. *Select Polyline icon. *Draw a rectangular with 10 meter for its sides. *Select Line icon. *Draw lines that present the diagonals of the rectangular. *Select Line icon again. *Draw Isosceles Triangular with 10 meter base to specify the height of the pyramid. *Draw a line that connects between the peak of the triangular and the midpoint of its base. *Select Vertical Dimension. *click on the endpoint of the vertical line to get its dimension which represent the height of the pyramid. *Select Pyramid from Toolbar. *Specify the number of pyramid's sides to 4 in command bar. *Choose circumscribed option in command bar. *Select the center point of the rectangular as the center point of the pyramid. *Specify the circumscribe of the pyramid which is equal to the circumscribe of the rectangular. *Specify the height of the pyramid by writing 10 meter in command bar. *Select the pyramid. *Select Copy icon from Toolbar. *Drag a copy of Pyramid. *Activate Left view. *Select Rotate icon from the toolbar. *Select the second pyramid and rotate it 180^0. *Drag it and connect to the base of the first pyramid. *Select Union operation from Boolean operations. *Select the two pyramids. *Click Enter.			

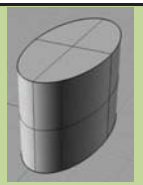
ArchiCAD	15.11.2010	00:18:19			* Click on Object in Toolbox. *Click on Object icon in the tool bar of Object. *In Folder list select: ArchiCAD Library 14> Special construction> Basic shapes. * Select Pyramid in the list. * Change parameters : No. of sides: 4 Cone Length: depend on the edge length (specific mathematic rules). End mode: Custom. Bottom Angle: 90 *Click OK. * Click anywhere in the view. *Copy the pyramid. *Go to story view. *Choose Multiply option>Drag. *Select the new pyramid. *Change parameters: Angle to XY Plane: 270. *Drag the pyramid and connect it with the other one. *Open Design menu. *Select solid element Operations. *Choose Addition operation. *Get Target. *Get Operator. *Click on Execute.	* No rotation option in elevation view.	*Boolean operation method.	
Revit Architecture	03.11.2010	00:26:29✕				*Used Sphere with dividing its surface, but couldn't find pentagonal system. *Try to create the pentagonal system by creating new curtain panel.		***Dodecahedron***
	03.11.2010	01:00:41✕				*Try dividing the dodecahedron to many small pyramids and connect them to bigger pyramids to connect them which will create dodecahedron.		
	08.11.2010	01:17:40✕				*Start with cube and adding pyramids to different faces of the cube.		
Rhino	16.11.2010	00:14:10		**727**	*Open Rhinoceros. *Choose Meter/inch file. *Select Line icon. *Activate Top view. *Select Polyline icon. *Draw a rectangular with 10 meter for its sides. *Activate Perspective view. *Select Cube icon from Toolbar. *Draw the base of the cube on the rectangular shape. *Create cube with specific length. *Activate Front view. *Select Line icon. *Draw a isosceles triangular with 30^0 on the top of the cube. *Activate Perspective view. *Select the triangular. *click on Copy icon. *Drag a copy of the triangular to the opposite side of the cube. *Select Line icon again. *Draw a line that connects the peak point of the two triangulars. *Activate Left view. *Select Line icon from Toolbar. *Draw a line that starts from the comer of the cube with 60^0. *Activate Perspective view. *Select Line icon. *Draw two lines that connect the point of intersection between the line of 60^0 and the horizontal line and with the corner point of the cube. That will create a sloped triangular with 60^0 with the cube. *Activate Right view. *Select Mirror icon form Toolbar. *Select the triangular and mirror a copy of it with center axis of the cube. *Activate Perspective view. *Select Line icon. *Draw a line that connects the peak points of the two triangulars. *Click on Surface menu> Planar Curve			

					*Select the lines of first triangular. *Click Enter. *Do the same with the second triangular. *Click on Surface menu> Planar Curve *Select Sweep 2 Rail. *Select the two triangulars and the line that them. *Click OK. *Write Join on command bar. *Select the surfaces of the created roof. *Activate Left view. *Select the roof. *Select Copy icon. *Drag a copy of the roof. *Select Rotate icon. *Rotate the copied roof vertically 90 0 and parallel to one of cube's sides. *Repeat the process again for each side of the cube. *Select Union icon. *Select all Dodecahedron parts. *Click Enter.			
ArchiCAD	15.11.2010	00:33:14✗ 00:27:48✗	00:07:22✗ 02:13:19✗ ✔		* Click on Object in Toolbox. *Click on Object icon in the tool bar of Object. *In Folder list select: ArchiCAD Library 14> Special construction> Basic shapes. * Select Cube in the list. * Change parameters. *Click OK. * Click anywhere in the view. * Click on Object in Toolbox. * Select House Model in the list. * Change parameters: Width Side Length Roof Angle:30 Gutter Height:00 Footing Height:00 * Click on Object in Toolbox. * Select Cube in the list. *Rotate the cube to 30. *Copy the cube by mirror command. * Copy the House Roof and two cubes and rotate them to each side of the cube. *On two of the cube sides, the Roof and 2 cubes should be rotated again. * Make the roof group. *Make the cubes in one group. *change roof group to specific layer. *Change cubes 'group to different layer. *Open Design menu and select > element operation. *Select Roofs as Target. *Select Cubes as operators. *Select Subtraction operation. *Click Execute. *Select Layer Settings in Toolbars. *Hide Cubes Layer. *Join all the parts of dodecahedron geometry by addition operation.	*Long operation and a lot of steps. *Rotation operation takes long time and a lot of steps. *Subtraction operation made holes in the geometry. *The resulted geometry was not perfect to use.	*Boolean operation method.	
Revit Architecture	08.11.2010	02:01:07✗				* Connecting two hexagon with Create Form command. *NURBS operations for Prism. *Dividing Anti-Prism to small pyramids *Subtracting pyramids from Prism by using Void forms.		***Anti-Prism***
	01.02.2011	00:40:02✗						
	01.02.2011 18.02.2011	00:31:43 ✔	00:20:15 ✔	**1382** **1429**	1. Open Revit Architecture. 2. *Choose New Conceptual Mass in families' files. 3. Choose Mass in the dialog. 4. Activate Lvel1 view. 5. Select Manage tab. 6. Click on Project Units icon. 7. Modify the units depending on what you want. 8. Click on Home tab. 9. Select one of Polygon icon in Draw panel. 10. To draw a polygon with 10 meter length side, you should calculate the diameter that can create such polygon. 11. Select the polygon.	*To Draw a polygon in Revit with specific side length, you should know the diameter first which need calculations and take time. *All the sides of Anti prism has same length, therefore you should calculate the height of Ant-prism to achieve that.		

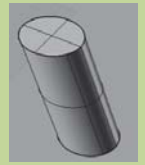
					12. Click on Rotate icon in Modify panel. 13. Modify rotation center to one of corner points of the polygon. 14. Rotate the polygon to make one of its side is parallel to X axis. 15. Select Line icon. 16. Draw lines that connect between the corner point to the midpoint of the opposite side of the polygon, that will help in specify the center point of the polygon. 17. Activate Elevation view. 18. Select the dashed line that present Level 1. 19. Press Ctrl. 20. Drag a copy of the level (Level 2). 21. Right click on Level 1 in Project Browser. 22. Choose Duplicate View> Duplicate. 23. Name the new level Level2. 24. Click OK. 25. Activate Level 1. 26. Select the polygon and the lines. 27. Click Copy icon in Modify panel. 28. Drag a copy a side. 29. Select the polygon and lines again. 30. In Modify/ Multi Select tab, Select Level 2 in Host bar. 31. Select Rotate from Modify panel. 32. *Place the rotation center on one of polygon's corner points. 33. Rotate the objects to make upper of polygon's side is parallel to X axis. 34. Drag the objects from center point to original polygon's center. 35. Activate 3D view to check that polygons are over each other. 36. Select Line icon. 37. Anti-prism with 10 meter polygon side, should has specific height, Draw a line that connects two opposite corner points of the two polygons. The length of that line should be 10 meter. 38. If the length of that line is not 10 meter, then you should change the distance between the two polygons to achieve that, so activate Elevation view. 39. Select the polygon in Level2. 40. Drag up or down depending on the length of the anti-prism side. 41. Activate 3D view. 42. Select the polygon at Level 1. 43. Click on Create Form> Solid Form. 44. Extrude the resulted prism to reach the upper polygon. 45. Select on one of vertical faces of the prism. 46. Click on Add Edge in Form element panel. 47. Draw an edge connect between the midpoint of the upper side of the selected face with the corner point of the face. 48. Select the resulted largest face on the previous face. 49. Click on Add Edge again. 50. Draw an edge connect between the midpoint of upper side of the face with the other corner point. 51. Activate Level 2. 52. Click on the point that divides the upper side of the previous face. 53. Drag it to corner point of Level 2 polygon. 54. Repeat the steps (48 - 53) to divide other four vertical faces. 55. In Level2, Select original corner points of the prism. 56. Drag them towards the center of the prism to create a side that connect between the new corner points of the anti-prism. 57. Repeat the previous step to other four corner points.		
Rhino	16.11.2011	00:08:57 ✔	00:13:08 ✔ Create Anti-prism with equilateral triangles faces.	**348** **601**	*Open Rhinoceros. *Choose Meter/inch file. *Select Line icon. *Go to Top view. *Select point on the view. *Specify the length of the line in Command bar. *Select Polygon: Edge icon. *Click on the end point of the line to draw the polygon. *Click on the other end point of the line to complete drawing the polygon. *Select Line icon. *Draw lines connects between the midpoints of polygon's sides. *Select Copy icon. *Select the polygon. *Drag a copy of the polygon. *Select Move icon. *Select the copied polygon. *Drag the polygon over the original one. *Select Rotate icon. *Select the copied polygon again.			

					*Rotate it 90^0. *Go to Front view. *Select the copied polygon. *Select Move icon. *Drag the polygon vertically for about 10 meter. *select Line icon. *Draw a line connects faced points in polygons. *Select Distance icon. *Measure the distance of the line that connects two points. It should be 10 meters measure. *If it is not; move one of the polygons to obtain the 10 meter distance Ant-prism side. *Select Line icon. *Draw lines connect the other points together to create the skeleton of anti-prism. *Select surface in menu>Planar Curves. *Select the first polygon. *Click enter. *Do the previous step to create plan for all Ant-prism faces. *Write Join in Command bar. *Select the surfaces of the ant-prism one by one.			
ArchiCAD	16.11.2010	00:53:04 ✗	00:15:44 ✔		* Click on Object in Toolbox. *Click on Object icon in the tool bar of Object. *In Folder list select: ArchiCAD Library 14> Special construction> Basic shapes. * Select Pyramid in the list. * Change parameters. *Click OK. * Click anywhere in the view. * Click on Object in Toolbox. *Click on Object icon in the tool bar of Object. * Select Pyramid again in the list. * Change parameters to the same previous Pyramid settings: Angle to XY plane:270 *Click OK. *Place the pyramid on the edges of the other pyramid exactly. *Rotate the pyramid. *Make each pyramid in different layer. *Open Design menu and select element operations. * Select one pyramid as target. *Other pyramid as operator. *Select Intersection operation. *Click Execute. *Hide the operator pyramid layer.	*Long time to figure out the solution.	*Boolean operation method.	
Revit Architecture	19.9.2010	00:14:00 ✔			*Open Revit Architecture. *Choose New Conceptual Mass in families' files. *Choose Mass in the dialog. *Select Manage tab. *Click on Project Units icon. *Modify the units depending on what you want. *Activate Level 1. *Click on Home tab. *Select circle icon in Draw panel. *Draw a circle on the view.		MM	***Truncated Cone*** 
	27.10.2010		00:02:00 ✔	**95**	*Activate elevation view. *Select Level 1 elevation dashed line. *Press Ctrl and drag a copy above. *Activate Level 1 view. *Right click on Level 1 in Project Browser dialog. *Select Duplicate View> Duplicate. *Name it Level 2. *Activate Level 2 view. *Select Circle icon. *Draw a circle that its center is the same center of previous circle with smaller diameter. *Activate 3D view. *If the smallest circle is still in Level 1, select it again. *Select level 2 in Host bar. *Select both circles. *Click on Create Form> Solid Form.		MM	

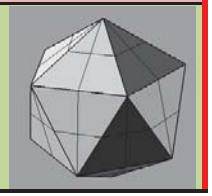
Rhino	09.11.2010		00:00:06 ✔	**15**	*Open Rhinoceros. *Choose Meter/inch file. *Activate Perspective view. *Specify the center of the cone. *Specify the radius of the cone. *Specify the height of the cone. *Specify the radius of the upper circle of the cone.			
ArchiCAD	09.11.2010	00:02:08			* Click on Object in Toolbox. *Click on Object icon in the tool bar of Object. *In Folder list select: ArchiCAD Library 14> Special construction> Basic shapes. * Select Cone in the list. * Change parameters: Top Circular Radius> More than 0. *Click OK. * Click anywhere in the view.		*Default Parametric Part of Cone.	
Revit Architecture	19.9.2010 18.02.2011	00:11:00	00:02:03 ✔	--- **163**	8 * Create an elliptical cylinder 5 *Select the upper or below surface of cylinder. *Select scale command in modify bar. *Scale the surface.		MM	***Semi. Elliptical Cone*** 
Rhino	09.11.2010		00:03:42 ✔	**184**	*Open Rhinoceros. *Choose Meter/inch file. *Activate Top view. *Click on Ellipse icon. *Specify the center of the ellipse. *Specify the radius of first ellipse. *Specify the radius of second ellipse. *Activate the Perspective view. *Select the ellipse. *open Surface> Planar Curves. *Click on Extrude Surface Tapered. *Select the surface. *Specify the height.			
Revit Architecture	26.10.2010		00:00:40		5 *Go too Level *Draw an ellipse. *Go to 3D view *Select the ellipse. *Create form.		MM	***Elliptical Cylinder*** 

Rhino	09.11.2010		00:00:40 ✔	**63**	*Open Rhinoceros. *Choose Meter/inch file. *Activate Top view. *Click on Ellipse icon. *Specify the center of the ellipse. *Specify the radius of first ellipse. *Specify the radius of second ellipse. *Activate the Perspective view. *Select the ellipse. *open Surface> Planar Curves. *Click on Extrude Surface icon. *Select the surface. *click enter. *Specify the height.			
ArchiCAD	09.11.2010	00:10:00			*Click on Arc in Toolbox. *Select Ellipse icon on default setting bar. * Draw Ellipse on any stories view. * Click on Slab in Toolbox. *Use Magic Wand to create slab with elliptic shape. *Click on the slab again. *Change parameters. *Open Story view. *Select the slab. *Go to: File>Libraries and Objects>Save Selection as. *Name the object and save. *Click on Object in Toolbox, you can find that the object was saved. *Change parameters. *Click Ok.			
Revit Architecture	20.9.2010 18.02.2011	00:44:00 ✘ 00:42:00 ✔	00:03:40 ✔	**347**	22 *Create a cone 10 *Create a polygon or rotated box: - go to elevation -Draw any shape can help. - go to 3D view -Select the shape. -Create a form. * Go to elevations and move the box or polygon to be placed with the cone. *Go to 3D view *select the box. *Change it to void. *Go to modify bar *Select Cut Geometry *Choose geometries to cut each other.	* 22 steps is the minimum steps, the steps can be more due to placing process. * After Cut Geometry process, if we select the Oblique Cone, the void geometry will appear in x ray mode. That's mean that the void geometry will be always connected to the resulted geometry and if deleted the original geometry will appear again.	GM GM	***Oblique Circular Cone*** 
Rhino	09.11.2010		00:04:33 ✔	**206**	*Open Rhinoceros. *Choose Meter/inch file. *Activate Perspective view. *Click on Cone icon in toolbar. *Specify the center of the cone. *Specify the radius of the cone. *Specify the height of the cone. *Activate Top view. *Select Surface menu>Plane> Corner to Corner. *Draw a rectangular plane that surround the cone. *Select the plane. *Activate the Left view. *Click on Move icon. *Move the plane vertically to the middle of the cone. *Click on Rotate icon. *Specify the first point of rotation. *Specify the second point of rotation. *Rotate the plane about 30^0. *Click on Boolean Split icon. *Select the cone as the surface to be split. *Press Enter. *Select the plane as the cutting surface. *Click Enter. *Select the lower part of the cone and the plane. *Press Delete.			

ArchiCAD	09.11.2010	00:01:14			* Click on Object in Toolbox. *Click on Object icon in the tool bar of Object. *In Folder list select: ArchiCAD Library 14> Special construction> Basic shapes. * Select Cone in the list. * Change parameters: Editing Mode" Angle-Length Bottom Angle. *Click OK. * Click anywhere in the view.			
Revit Architecture	19.9.2010 18.02.2011 18.02.2011	02:11:00 00:01:53 ✔	00:02:20 ✔	**186** **201**	26 - Create an oblique Cylinder: *Go to Level *create a circle *go to elevation *Draw an oblique line *Go to 3D * move the line to center of circle *Select the line *set an oblique work plane?? *Draw an oblique circle *Select the circle. *Create Form - Create a semi cone 11 * Move the oblique cylinder over the semi cone dependent on what RC cone the designer like. *dissolve command doesn't work *Select Cylinder *In properties, change it to Void. *Cut Geometry	* Create levels only work in elevations or sections. * Difficulties with creating work plane, it takes long time to create it. *Cutting the geometry without change it to void, doesn't work, because it will still appear and connect with the other geometry, and if deleted it the cut geometry process will be cancelled. *Boolean operations in Revit only limited in Join and Cut.	MM	***Right Circular Cone*** 
Rhino	09.11.2010		00:04:33 ✔	**206**	*Open Rhinoceros. *Choose Meter/inch file. *Activate Perspective view. *Click on Cone icon in toolbar. *Specify the center of the cone. *Specify the radius of the cone. *Specify the height of the cone. *Activate Top view. *Select Surface menu>Plane> Comer to Corner. *Draw a rectangular plane that surround the cone. *Select the plane. *Activate the Left view. *Click on Move icon. *Move the plane vertically to the middle of the cone. *Click on Rotate icon. *Specify the first point of rotation. *Specify the second point of rotation. *Rotate the plane about 30^0. *Click on Boolean Split icon. *Select the cone as the surface to be split. *Press Enter. *Select the plane as the cutting surface. *Click Enter. *Select the upper part of the cone and the plane. *Press Delete.			
ArchiCAD	09.11.2010	00:01.18			* Click on Object in Toolbox. *Click on Object icon in the tool bar of Object. *In Folder list select: ArchiCAD Library 14> Special construction> Basic shapes. * Select Cone in the list. * Change parameters: Top Circular Radius>More than 0. Top angle. *Click OK. * Click anywhere in the view.			
Revit Architecture	26.10.2010 18.02.2011		00:01:40 00:00:50 ✔	**67**	6 * Select level * Draw a Circle. *Go to 3D view. *Select circle. * create Form. *Select upper face.		MM	***Oblique Circular cylinder***

					*Move it.			
Rhino	09.11.2010		00:02:11 ✔	**141**	*Open Rhinoceros. *Choose Meter/inch file. *Select Line icon. *Activate Top view. *Click on Circle; Center, Radius icon. *Specify the center and the radius of the circle on the view. *Activate Left view. *Click on Line icon. *Draw a vertical slope line that starts from a point on the circumscribe of the circle. *Activate Perspective view. *Select the circle *Select Surface>Planar curves. *Click on Extrude Surface Along Curve icon. *Select the circle as the surface to extrude. *Press Enter. *Select the line as the path of extrusion. *Click enter.			
ArchiCAD	09.11.2010	00:02:46			* Click on Object in Toolbox. *Click on Object icon in the tool bar of Object. *In Folder list select: ArchiCAD Library 14> Special construction> Basic shapes. * Select Cylinder in the list. * Change parameters: End mode: Custom. Bottom Angle. Top angle. *Click OK. * Click anywhere in the view.			

c. Complex Solids:

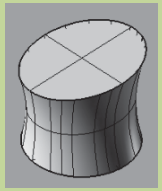
Comparison Factor / *Software*	*Date*	*Time*		*Clicks*	*Steps*	*Difficulties*	*Notes*	*Comparison Factor* / *Geometries*
		1st Time	*2nd Time*					
Revit Architecture	01.02.2011	00:31:43 ✔ Create Anti-Prism. 00:21:04 ✘ Create two pyramids and connect them to Anti-Prism geometry.						***Icosahedron***
Rhino	16.11.2010	00:09:05 ✔ Create Anti-Prism. 00:14:21 ✔ Create two pyramids and connect them to Anti-Prism geometry.		**526** **682**	*Create Anti-Prism:* *Open Rhinoceros. *Choose Meter/inch file. *Select Line icon. *Go to Top view. *Select Polygon: Edge icon. *Write 5 as Number of polygon's sides. *Select point on the view to start create the polygon. *Write 10 meter in Command bar to specify the length of polygon's side. *Press on Shift and select the end point of polygon's side.			

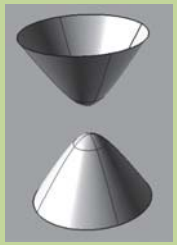
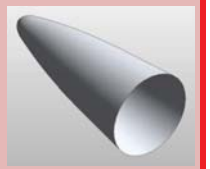
					*click on Copy icon. *Select the polygon. *Drag a copy. *Select the polygon again. *Click on Move icon. *Drag the new polygon to be applicable on the original one. *Click on Rotate icon. *Select the polygon. *Click on the center of the polygon to rotate 45^0. *Activate Front view. *Click on Move icon. *Drag the polygon vertically (try to drag the new polygon to achieve a distance 10 meter as the vertical side of the anti-prism). *Click on Distance icon. *Calculate the distance between the points that create the vertical side of the anti-prism, make sure it equals 10 meter. *Click on Line icon. *Draw lines that represent the sides of Anti-prism. *Click on Surface in menu bar>Planar Curves. *Select the polygon. *Click Enter. *Do the previous steps to create the sides of the anti-prism. *Write Join in Command bar. *Select the sides of the anti-prism. *Press Enter. *Create Icosahedron:* *Select Polygon: Edge icon. *Write 5 as Number of polygon's sides. *Select point on the view to start create the polygon. *Write 10 meter in Command bar to specify the length of polygon's side. *Press on Shift and select the end point of polygon's side. *Select Line icon. *Draw lines that connect each corner point of the polygon with its opposite midpoint. *Select Distance icon. *Calculate the distance between the any corner point with the center point. *Try to use Pythagoras theorem to calculate the height of the pyramid. *Select Line icon. *Draw a vertical line that present the height of the pyramid which starts from the center point of the polygon. *Select Line icon again. *Draw lines connect between the end point of the vertical line with the comer points of the polygon. *Click on Surface in menu bar>Planar Curves. *Select the polygon. *Click Enter. *Do the previous steps to create the sides of the anti-prism. *Write Join in Command bar. *Select the sides of the anti-prism. *Press Enter. *Select Move icon. *Select the pyramid. Drag it to be applicable on the ant-prism. *Activate Front view. *Select Mirror icon. *Select the pyramid again. *Draw a horizontal line that represents the mirror axis. *Select move icon. **Select the resulted pyramid. *Drag it to be applicable on the other side of the ant- prism. *Write Join in Command bar. *Select the ant-prism + pyramids. *Press Enter.			

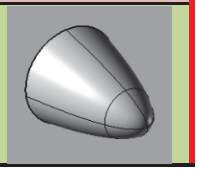
Surfaces:

a. Preliminary Surfaces:

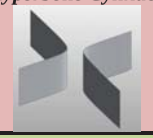
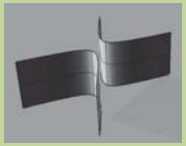
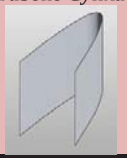
Comparison Factor / *Software*	*Date*	*Time* 1st Time	*Time* 2nd Time	*Clicks*	*Steps*	*Difficulties*	*Notes*	*Comparison Factor* / *Geometries*
Revit Architecture	19.9.2010	00:25:00			13 *Go to level *Create a Circle. *duplicate level in Project browser. *Rename level to level2 *Go to elevation. *Duplicate level1 *Create an oblique line *Go to 3D view *Select line *Set the work plane?? *Draw a circle on the oblique plane. *Select two circles *Create Form	* Work Plane setting take longer time than considered as one step, sometimes it takes 3 or 4 steps to set it.	MM	***One Sheet Hyperboloid*** 
	15.11.2010	00:43:40 ✔		**1912**	***Creating Hyperbola curves:*** *Open Revit Architecture. *Choose New Conceptual Mass in families' files. *Choose Mass in the dialog. *Select Manage tab. *Click on Project Units icon. *Modify the units depending on what you want. *Activate Level 1. *Click on Home tab. *Select Line icon. *Draw Line represent X axis. *Draw perpendicular line represent Y axis. *Select Point Element icon in draw panel. *Use Point element icon on Draw panel to divide axis lines to specific distance represent the coordinates of axis. *Calculate the coordinates of Hyperbola curve. *Select Point Element icon. *Draw points that represent the coordinates of hyperbola curve on the axis. *Select Spline Through points icon in Draw panel. *Draw a spline that connects the points to create hyperbola curve. *Select the resulted curve. *Select Mirror-Draw Axis icon in modify panel. *Check Copy box. *Draw the mirror axes following X axis. *Select the resulted curve. *Select Mirror-Draw Axis icon. *Draw mirror axis following the line that represents the infinity point of hyperbola curve (∞).	*There is a lot of calculation operations which takes time. *I look tired in that experiment and did a lot of calculation mistakes that is why it took long time to work.	MM	
	15.11.2010	00:15:04 ✔		**526**	* Select Line icon. *Draw a line that connects the two curves in peek point, *Draw a perpendicular line to the previous line starting with its midpoint to create a symmetrical axis to two curves. *Select one of the curves and the axis line. *click on Create Form> Solid Form. *choose hyperboloid option that Revit offers.		MM	

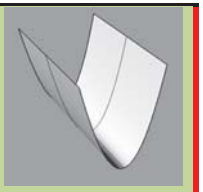
Rhino	09.11.2010	00:03:35			*Go to Left view. *Open Curve menu. *Select Hyperbola (Center, Focus). *Draw the hyperbola on the view. *Go to Perspective view. *Select the circle from the toolbar. *Draw a circle connected to the end of hyperbola. *Select the circle. *Select copy command. *Drag a copy of the circle to the other end of Hyperbola. *Open surface menu. *Select Planar curve. *Select the first sphere. *Select Planar curve again. *Select the other circle. *Open surface menu again. *Select Sweep 2 trail. *Select first surface. *Select second surface. *Select hyperbola. *Click Enter. *Click OK. *Write Join in Command bar. Select the surfaces. *Click Enter to make the Hyperboloid a volume.			
	03.02.2011	00:14:14		**114**	*Open Rhinoceros. *Choose Meter/Inch file. *Click on Curve (menu)> Hyperbola>Center, Focus. *Select a point in Top view. *Select another point on Top view. *Choose the appropriate shape for the Hyperbola curve and click Enter. *Select the curve again. *click on Mirror icon. *Draw the axis of mirror operation. *Select Line icon. *Draw a line connect between the peek points of the two curves. *Select Line icon. *Click on Midpoint of the connected line. *Draw perpendicular line. *Select Line icon.' *Draw a line at the other side of the perpendicular line. *Select Extend Curve icon. *Select the random line. *Click on the perpendicular line. *Select the random line. *Press Delete. *Go to Front view *Select Rotate icon. *select the point of one side of axis line. *Select the other point from the other side. *Rotate vertically (90^0). *Go to perspective view. *Select the curves and axis line. *Select Surface on menu>Revolve. *Select one curve. *Press Enter. *Draw the axis of Revolve operation. *Press Enter. *Revolve (360^0). *Press Enter.			
Revit Architecture	15.11.2010	00:06:36 ✔		**474**	***Create hyperbola curves.***			***Two Sheets Hyperboloid***

					*Click on line icon in Draw bar. *Draw line connect between the midpoint of hyperbola curves and perpendicular to the axis of hyperbola curves. This line is the perpendicular axis for hyperbola curves. *Select one of hyperbola and the perpendicular axis. *Click on Create form> Solid Form. *Select other hyperbola. *Select the axis. *Click on Create Form> Solid Form.			
Rhino	03.02.2011	00:10:19		**140**	*Open Rhinoceros. *Choose Meter/Inch file. *Click on Curve (menu)> Hyperbola>Center, Focus. *Select a point in Top view. *Select another point on Top view. *Choose the appropriate shape for the Hyperbola curve and click Enter. *Select the curve again. *click on Mirror icon. *Draw the axis of mirror operation. *Select Line icon. *Draw a line connect between the peek points of the two curves. *Select Line icon. * Draw a line at the side of Hyperbola curves. *Select Line icon. *Draw a line on the opposite side of the curves. *Select Extend Curve icon. *Select the lines on the sides. *Click Enter. *Click on the line that connect between curves, *Click again to extent the line. *Select the lines on the sides. *Press Delete. *Select the curves and axis line. *Go to Front view. *Select Rotate icon. *Select the point on one side of the axis. *Select on the point of the other side of the axis. *Rotate the line vertically. *Go to Perspective view. *Select Surface from the menu>Revolve. *Select two curves. *Press Enter. *Draw the axis for Revolve. *Press Enter. *Follow Revolve for 360^0. *Press Enter.			
Revit Architecture	02.02.2011	00:10:29 ✔ Create Parabola curve 00:05:30 ✔ Create Paraboloid		**317** **226**	*Create Parabola curve:* 1. Open Revit Architecture. 2. Choose New Conceptual Mass in families' files. 3. Choose Mass in the dialog. 4. Select Manage tab. 5. Click on Project Units icon. 6. Modify the units depending on what you want. 7. Activate Level 1. 8. Click on Home tab. 9. Select Line icon. 10. Draw Line represent X axis. 11. Draw perpendicular line represent Y axis. 12. Select Point Element icon in draw panel. 13. Divide axis lines to specific distance represent the coordinates of axis. 14. Calculate the coordinates of Parabola curve. 15. Select Point Element icon. 16. Draw points that represent the coordinates of parabola curve on the axis. 17. Select Spline Through points icon in Draw panel. 18. Draw a spline that connects the points to create parabola curve. *Create Paraboloid:*			***Paraboloid*** 

					*Select the spline. *Click on Copy icon. *Drag a copy of the spline. *Select Line icon. *Draw a line that divide the parabola curve to two identical parts. *Activate 3D view. *Select the curve and the line. *Click on Create Form>Solid Form.			
Rhino	09.11.2010	00:00:12 ✔		22	*Open Rhinoceros. *Choose Meter/inch file. *Activate Perspective view. *Click on Paraboloid icon. *Specify the paraboloid focus point. *specify paraboloid direction. *specify paraboloid radius.			

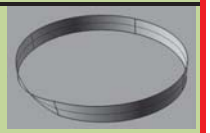
b. Secondary Surfaces:

Comparison Factor / *Software*	*Date*	*Time* 1st Time	*Time* 2nd Time	*Clicks*	*Steps*	*Difficulties*	*Notes*	*Comparison Factor* / *Geometries*
Revit Architecture	15.11.2010	00:07:14 ✔		571	***Create hyperbola curve.*** *Select two hyperbola curves. *Click on Create Form> Solid Form.			***Hyperbolic Cylinder*** 
Rhino	03.02.2011	00:02:58 Create Hyperbola curve ✔ 00:01:04 Create Hyperbola Cylinder ✔		57 28	*Open Rhinoceros. *Choose Meter/inch file. *Click on Curve (menu)> Hyperbola>Center, Focus. *Select a point in Top view. *Select another point on Top view. *Choose the appropriate shape for the Hyperbola curve and click Enter. *Select the curve again. *click on Mirror icon. *Draw the axis of mirror operation. *Select both curves. *Click on Extrude Closed Planar Curve icon. *Select the height of the extrusion.			
Revit Architecture	02.02.2011	00:10:29 ✔ Create Parabola curve 00:00:11 ✔ Create Parabolic Cylinder		317 6	*Create Parabola curve.* *Create Paraboloid Cylinder:* *Activate 3D view. *Select the spline. *Click on Create Form>Solid Form.			***Parabolic Cylinder*** 

Rhino	03.02.2011	00:00:27 ✔ Create Parabola curve 00:01:59 ✔ Create Paraboloid Cylinder		7 90	*Open Rhinoceros. *Choose Meter/inch file. *Click on Curve (menu)> Parabola>Focus, Direction. *Select a point in Top view. *Select another point on Top view. *Choose the appropriate shape for the Parabola curve and click Enter. *Select Line icon. *Draw a Line that can be the axis of parabola curve. *Select the curve and the axis in Top view. *Select Rotate icon. *Go to Front view. *Select the point at the side of axis. *Select the other point at the other side of the axis. *Rotate vertically. *Go to Perspective view. *Select the curve. *Select Extrude Closed Planar Curve icon. *Specify the distance of extrusion. *Click Enter.			
Revit Architecture	02.02.2011	00:10:29 ✔ Create Parabola curve 00:13:28 ✔ Create Elliptic Paraboloid.		599	***Create Parabola curve.*** ***Create Elliptic Paraboloid:*** 1. Click Reference in Draw panel. 2. Select Line icon in Draw panel. 3. Draw a line that connect the end points of parabola curve. 4. Select the line. 5. Click on Set in Work Plane panel. 6. Click on Show in Work Plane panel. 7. Select Ellipse icon in draw panel. 8. Draw an ellipse that its center the midpoint of reference line, and its first diameter is the length of the line. 9. Specify the second diameter which it can be longest than the first diameter. 10. Click on Spilt element in Modify panel. 11. Split the ellipse from the points that connect it with parabola curve. 12. Select half of the ellipse and the reference line. 13. Press Delete. 14. Select the half ellipse and parabola curve. 15. Click on Create Form>Solid Form. 16. Activate elevation view. 17. Select the created surface. 18. Click on Mirror - Draw Axis icon in Modify panel. 19. Check Copy box in Modify bar. 20. Draw the axis of mirror operation.	*Ellipse can be drawn only by specify the center, there is no other option to draw it by specify its diameter first.		***Elliptic Paraboloid*** 
Rhino	03.02.2011	00:00:27 ✔ Create Parabola curve 00:12:27 ✔ Create Elliptic Paraboloid		7 401	*Open Rhinoceros. *Choose Meter/inch file. *Click on Curve (menu)> Parabola>Focus, Direction. *Select a point in Top view. *Select another point on Top view. *Choose the appropriate shape for the Parabola curve and click Enter. Select Line icon. *Draw a Line that can be the axis of parabola curve. *Select the curve and the axis in Top view. *Select Rotate icon. *Go to Front view. *Select the point at the side of axis. *Select the other point at the other side of the axis. *Rotate vertically. *Go to Top view. *Select Ellipse: From Center icon. *Select the center of the ellipse on the axis of the parabola. *Specify the first diameter. *Specify the second diameter. *Select Line icon. *Draw a line connect between the end points of parabola. *Select Split icon. *Select the ellipse to split it. *Select the line as cutting object. *Click Enter.			

					*Select one side of cut ellipse. *Press Delete. *Go to Perspective view. *Select Curve menu>Rail Revolve. *Select curves as rail curves. *click Enter. *Specify the Revolve axis. *click Enter.			

c. Complex Surfaces:

Comparison Factor / *Software*	*Date*	*Time* 1st Time	*Time* 2nd Time	*Clicks*	*Steps*	*Difficulties*	*Notes*	*Comparison Factor* / *Geometries*
Revit Architecture	18.02.2011		00:21:14 ✔	1629	1. Open Revit Architecture. 2. Choose New Conceptual Mass in families' files. 3. Choose Mass in the dialog. 4. Select Manage tab. 5. Click on Project Units icon. 6. Modify the units depending on what you want. 7. Activate Level 1. 8. Click on Home tab. 9. Select Ellipse icon. 10. Specify the center of the ellipse on the view. 11. Specify the first radius of the ellipse. 12. Specify the second ellipse. 13. Select Line icon. 14. Check 3D snapping in Modify/ Place Lines tab. 15. Draw a line that connects between the quads that connect the shortest radius of the ellipse. 16. Select Split Element icon in Modify Lines tab. 17. Split the ellipse in the end point of the line. 18. Select the upper part of the ellipse. 19. Activate 3D view. 20. Click on Create Form> Solid Form 21. Activate Level 1 view. 22. Select the created form. 23. Select Mirror-Draw axis in Modify panel. 24. Activate 3D view. 25. Select the line that presents the edge of one of the created surfaces. 26. Activate Elevation view. 27. Select Rotate icon in Modify panel. 28. Specify the center of rotation in the center of the line. 29. Rotate the line 110^0 clockwise. 30. Select the opposite edge in the second surface. 31. Select Rotate icon. 32. Specify the center of rotation in the center of the line. 33. Rotate the line 70^0 anticlockwise or connect it with the other edge of the first surface.			***Mobuis Strip*** 
Rhino	03.02.2011	00:31:58 ✘						
	03.02.2011 18.02.2011	00:05:19 ✔	00:07:27 ✔	605	*Open Rhinoceros. *Choose Meter/inch file. *Select Ellipse: Diameter icon. *Specify the first diameter of the ellipse in Top view. *Specify the second diameter of the ellipse. *Select Line icon. *Draw a line connect between the points that specify the first diameter of the ellipse, *Select Split icon. *Select the ellipse to split it. *Select the line as the cutting object. *Select one of the half sided of the ellipse. *Select Copy icon. *Drag a copy of the half ellipse. *Go to Perspective view. *Selected the copied half ellipse.			

					*Select Extrude Closed Planar Curve icon. *Specify the height of the extrusion. *Select the resulted surface. *Select Controls Points On icon. *Switch the places of the points on the edge of the surface. *Select the curve again. *Select Copy icon. *Drag a copy of the curve. *Go to Top view. *Select Mirror icon. *Mirror the copied curve. *Select Move icon. *Drag the curve and connect it to the surface. *Go to Perspective view. *Select Extrude Closed Planar Curve icon. *Extrude the curve to same height of other surface. *Select the new surface. *Select Control points On icon. *try to connect the two surfaces together.			

Configuration & Transformation Stage:

Comparison Factor / Software	Date	Time 1st Time	Time 2nd Time	Clicks	Steps	Difficulties	Notes	Comparison Factor / Geometries
Revit Architecture	18.02.2011	00:18:32 ✔		1104				
Rhino	18.02.2011	00:10:04 ✔		677				

Load & Export Process:

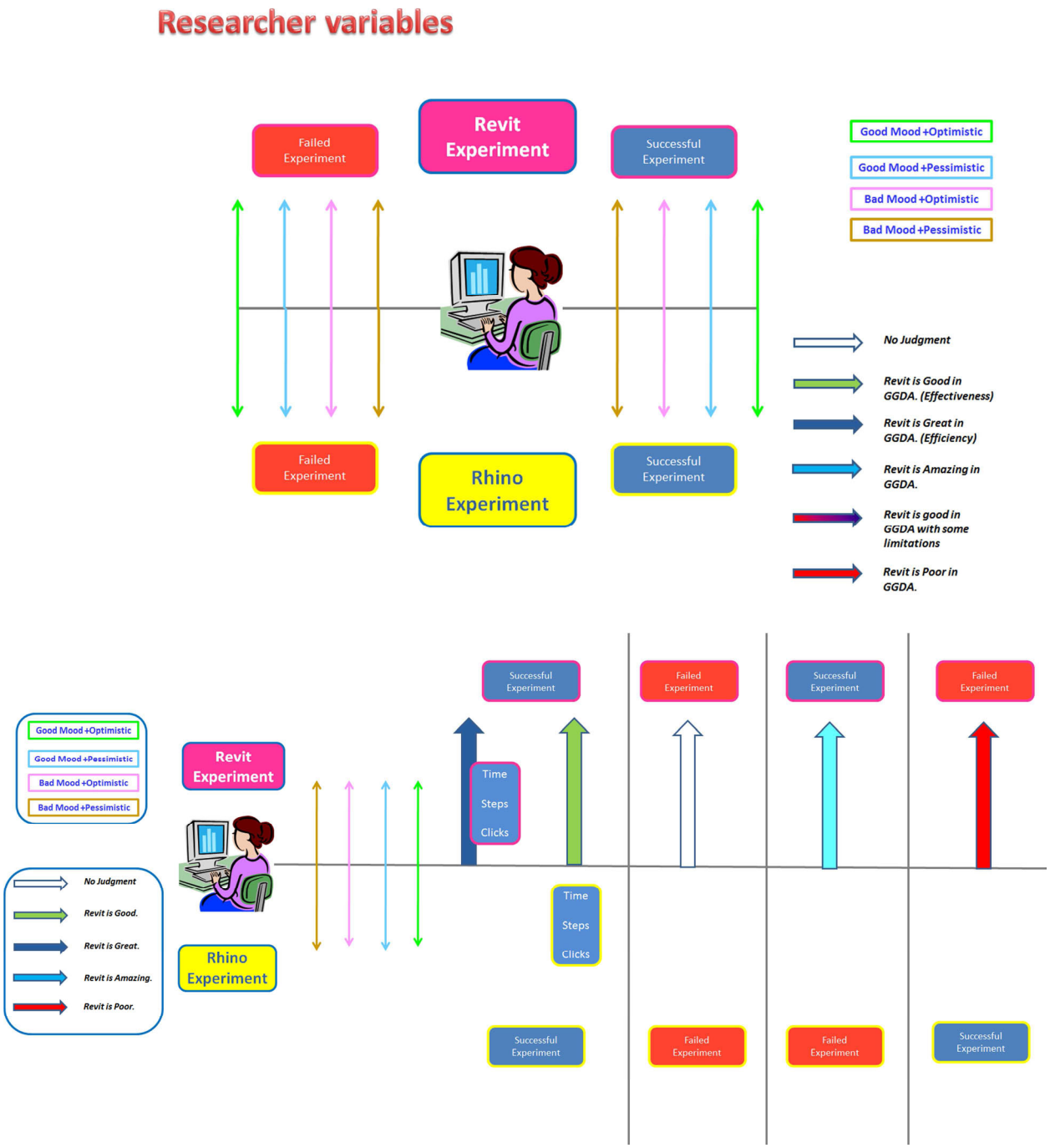
Comparison Factor / Software	Date	Time 1st Time	Time 2nd Time	Clicks	Steps	Difficulties	Notes	Comparison Factor / Geometries
Revit Architecture	18.02.2011	00:00:28 ✔		17	1. Click Open icon> New> Project. 2. Click OK in the diagram. 3. Open Revit Architecture. 4. Select Manage tab. 5. Click on Project Units icon. 6. Modify the units depending on what you want. 7. Go back to Mass file. 8. Click on Load into Project icon in Modify tab. 9. In Project file, click on Place on work Place icon in Placement panel in Modify tab.			
Rhino	18.02.2011	00:03:13 ✔		120	1. Select all the created mass in Rhinoceros. 2. Click on File>Export Selected... 3. Click on Save as Type list to select the extension of the file. 4. Select ACIS (*.sat). 5. Write the name in File name box. 6. Click OK in the dialog. 7. Click OK again for the next dialog. 8. Open Revit Architecture. 9. Choose New Conceptual Mass in families' files. 10. Choose Mass in the dialog. 11. Select Manage tab. 12. Click on Project Units icon. 13. Modify the units depending on what you want. 14. Click Insert tab>Import CAD. 15. Select the export SAT file from Rhinoceros. 16. Click Open. 10. Click Open icon> New> Project. 11. Click OK in the diagram. 12. Open Revit Architecture. 13. Select Manage tab. 14. Click on Project Units icon. 15. Modify the units depending on what you want. 16. Go back to Mass file. 17. Click on Load into Project icon in Modify tab. 18. In Project file, click on Place on work Place icon in Placement panel in Modify tab.			

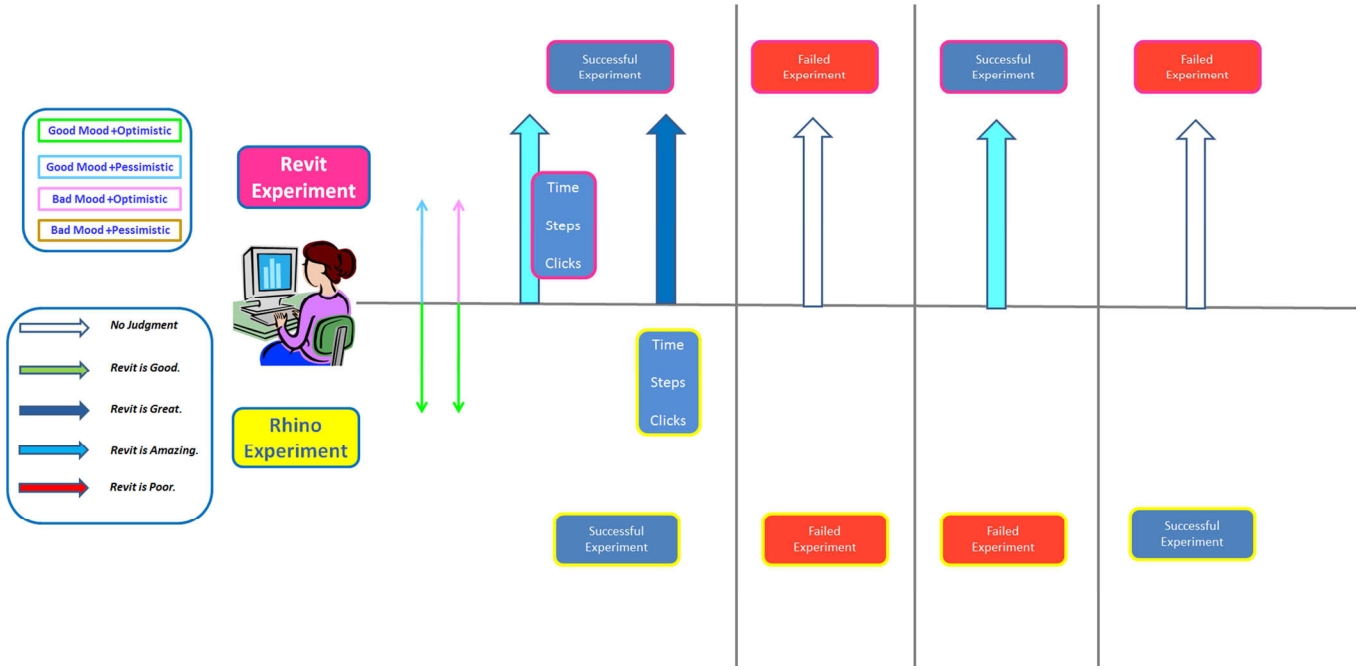
* Mass Model (MM) * Generic Model (GM)
*Successful try ✔ * Failed try ✕

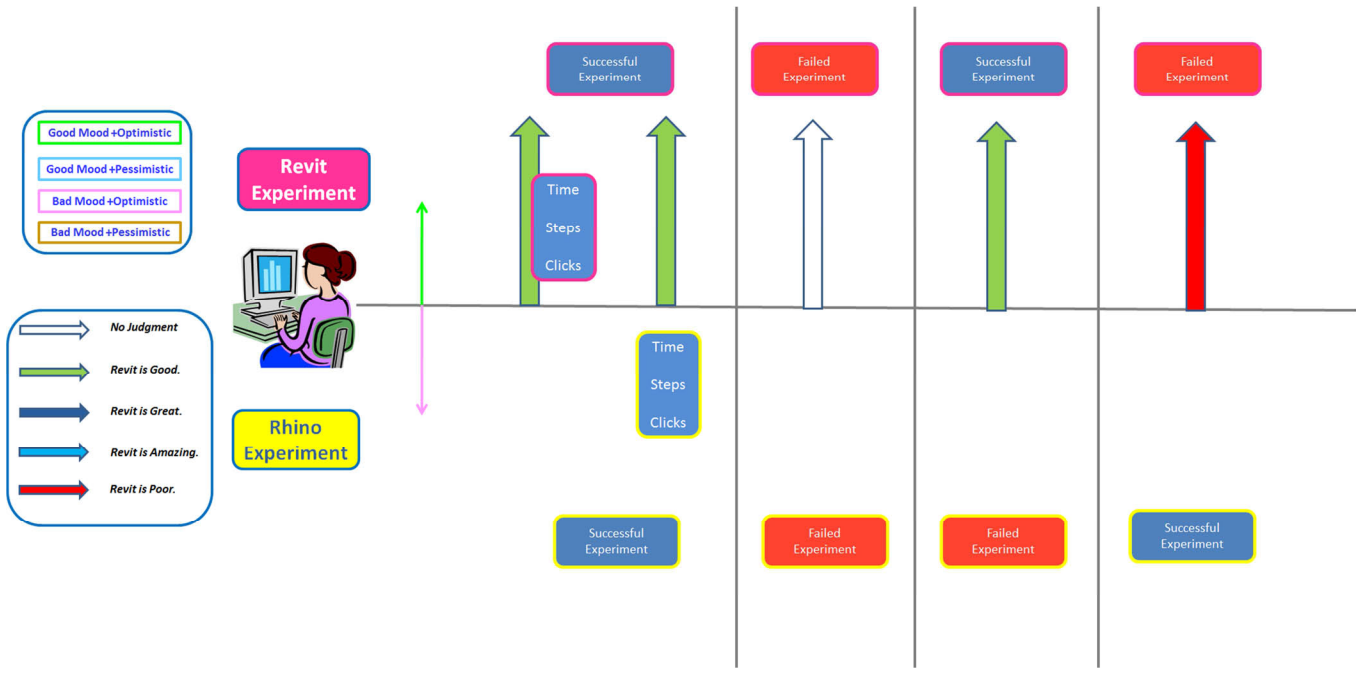
Appendix C.1

Researcher IndVs

The Analysis Strategy of the Main Method



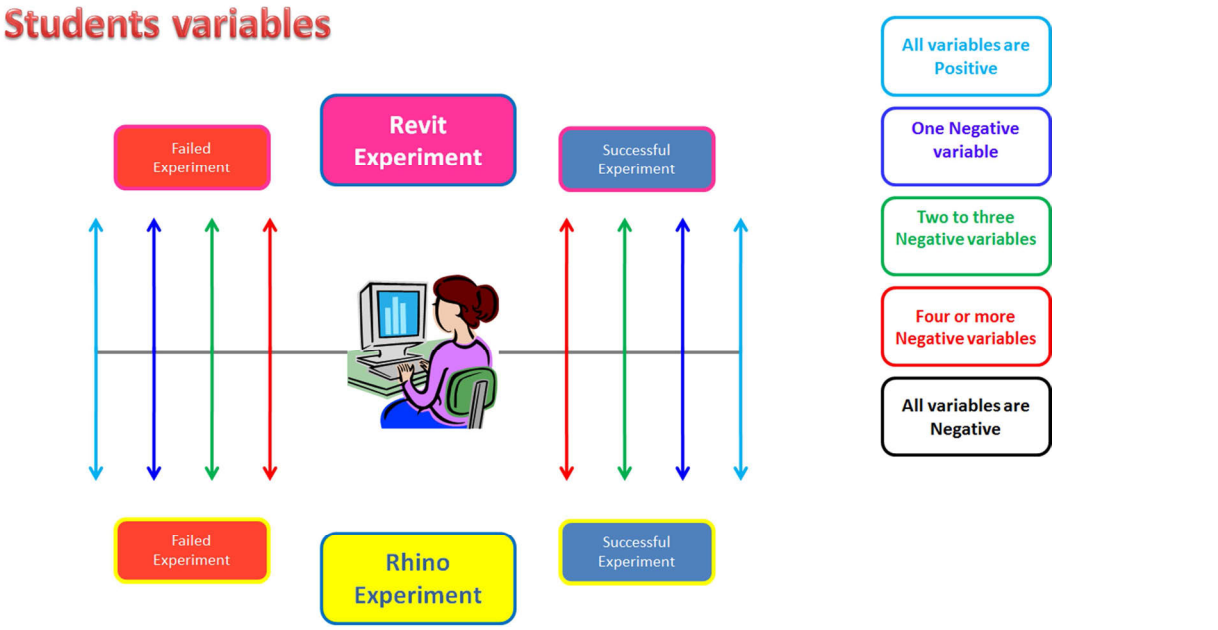

Good Mood +Optimistic
Good Mood +Pessimistic
Bad Mood +Optimistic
Bad Mood +Pessimistic
No Judgment
Revit is Good.
Revit is Great.
Revit is Amazing.
Revit is Poor.
Revit Experiment
Rhino Experiment
Time
Steps
Clicks
Successful Experiment
Failed Experiment
Successful Experiment
Failed Experiment
Time
Steps
Clicks
Successful Experiment
Failed Experiment
Failed Experiment
Successful Experiment

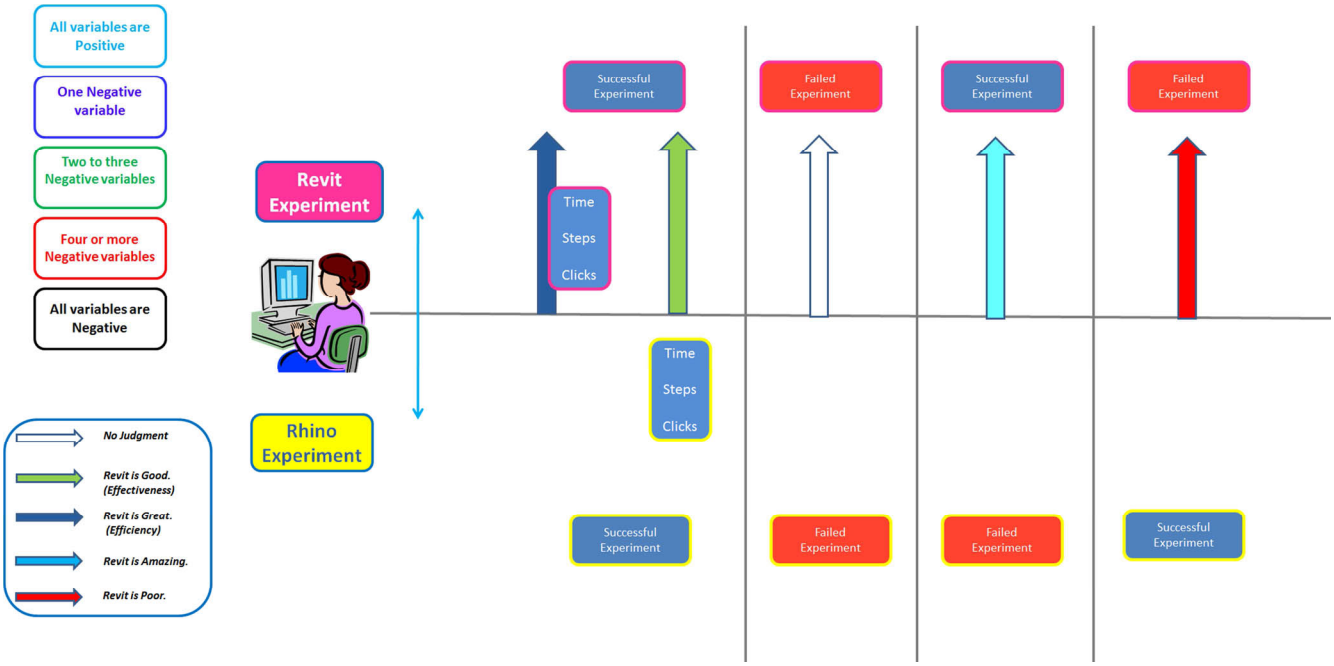

Good Mood +Optimistic
Good Mood +Pessimistic
Bad Mood +Optimistic
Bad Mood +Pessimistic
No Judgment
Revit is Good.
Revit is Great.
Revit is Amazing.
Revit is Poor.
Revit Experiment
Rhino Experiment
Time
Steps
Clicks
Successful Experiment
Failed Experiment
Successful Experiment
Failed Experiment
Time
Steps
Clicks
Successful Experiment
Failed Experiment
Failed Experiment
Successful Experiment

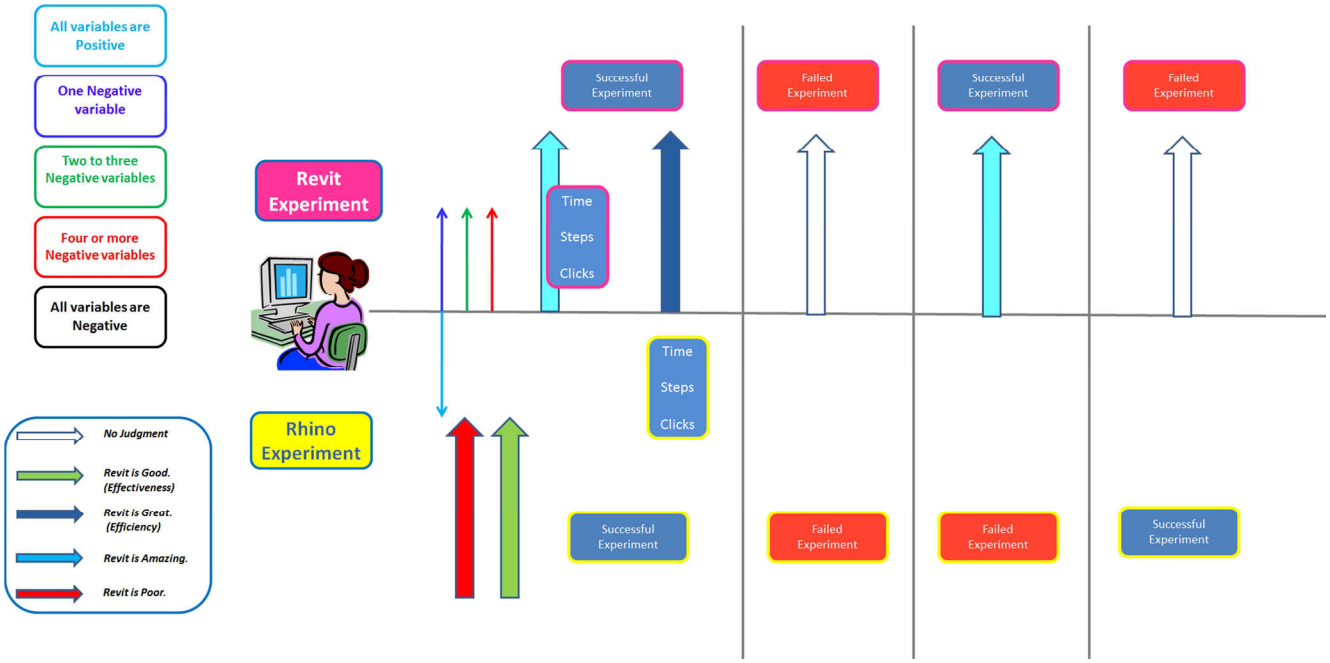
Appendix C.2

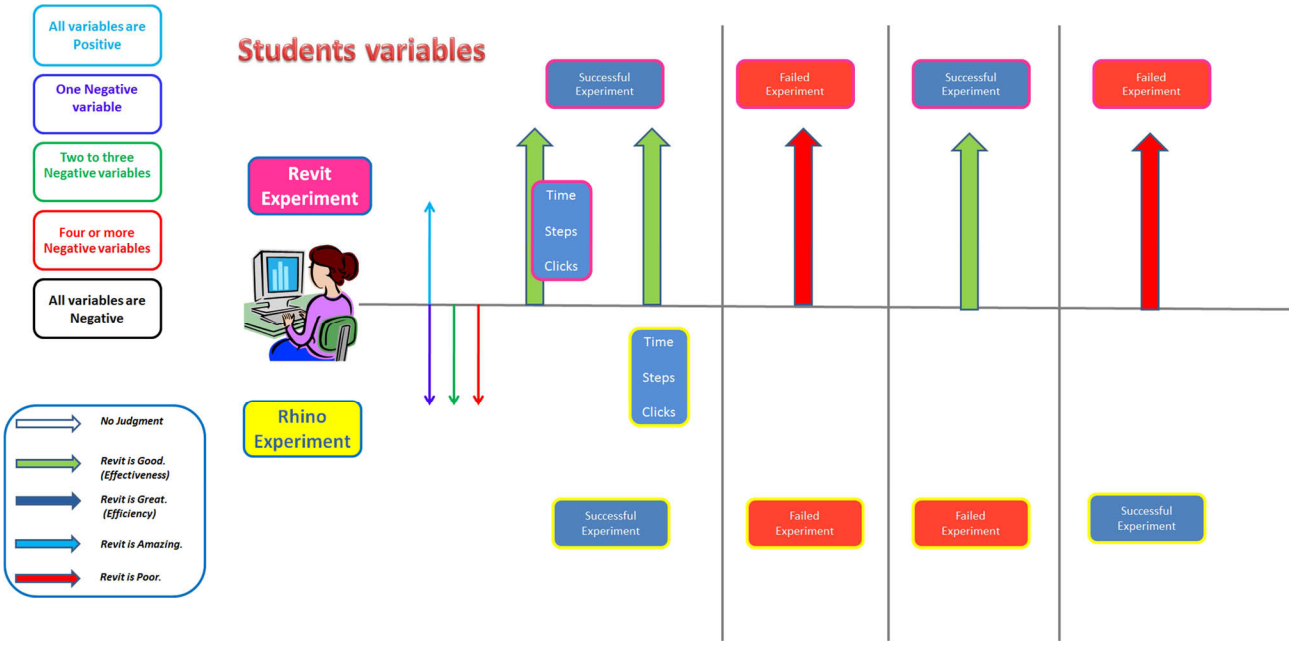
Students IndVs

The Analysis Strategy of the Confirmation Method



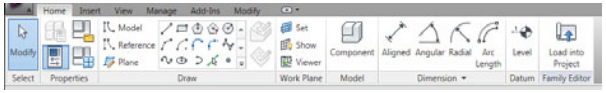
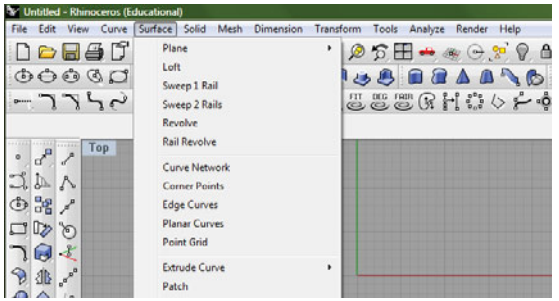
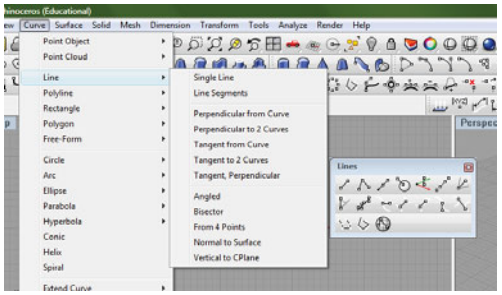


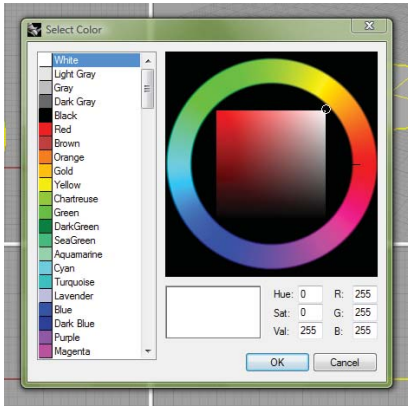
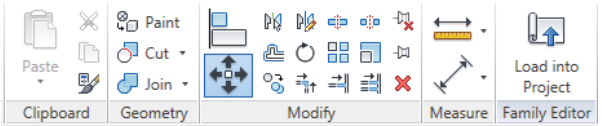
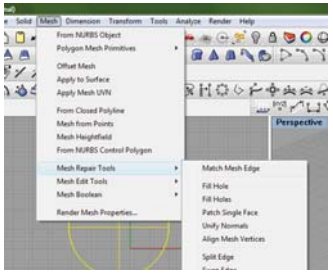

All variables are Positive
One Negative variable
Two to three Negative variables
Four or more Negative variables
All variables are Negative
No Judgment
Revit is Good. (Effectiveness)
Revit is Great. (Efficiency)
Revit is Amazing.
Revit is Poor.
Revit Experiment
Rhino Experiment
Time
Steps
Clicks
Successful Experiment
Failed Experiment

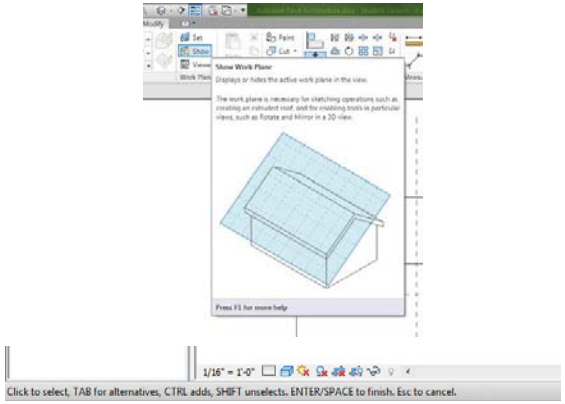
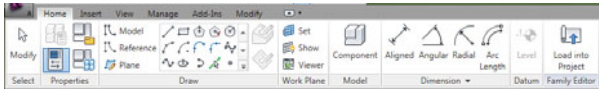
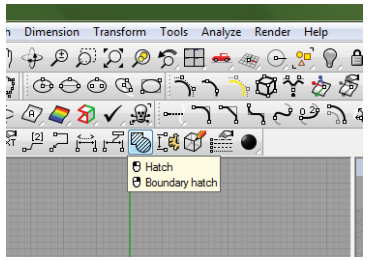
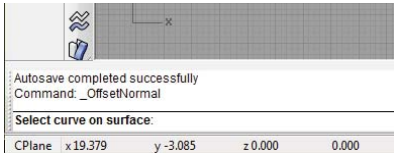
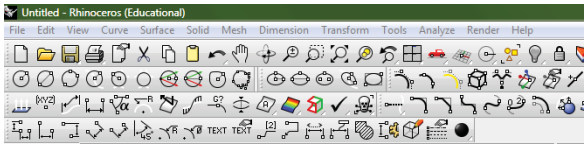
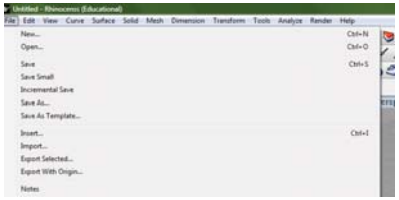

Students variables
All variables are Positive
One Negative variable
Two to three Negative variables
Four or more Negative variables
All variables are Negative
No Judgment
Revit is Good. (Effectiveness)
Revit is Great. (Efficiency)
Revit is Amazing.
Revit is Poor.
Revit Experiment
Rhino Experiment
Time
Steps
Clicks
Successful Experiment
Failed Experiment

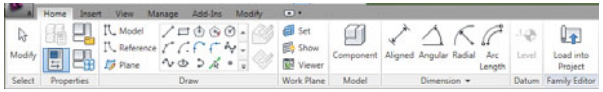
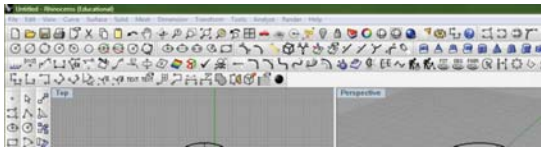
Appendix D

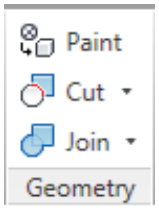
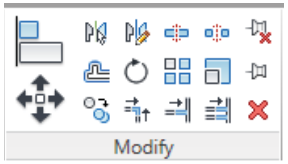
The Comparison Between the Interfaces of Revit Architecture & Rhinoceros

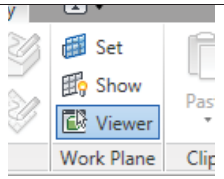
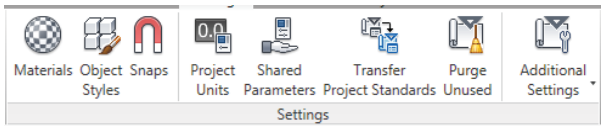
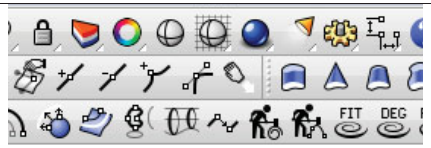
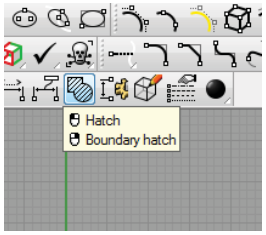
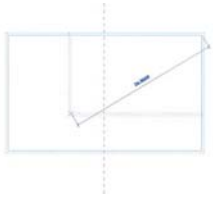
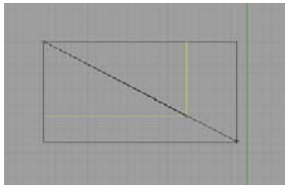
Usability Evaluation Questions (Lin et al. 1997, 276-277)	**Explanation** (Smith and Moiser)	**Revit Architecture 2011 (MMF)**	**Rhinoceros**
Compability		**2.5**✓	**3**✓
Is the control of cursor compatible with movement?	Control of cursor is compatible with movement.	✓Yes	✓Yes
Is the wording familiar?	Wording Familiarity: * The wording of displayed data and labels should incorporate familiar term. * There is no ambiguity.	∞Not all  Some expressions in Revit interface are not clear to beginners. the user will understand them after practicing Revit. - Work Plane -Datum -Inquiry -Marcus	✓Yes  The expressions in Rhinoceros are clear: Curve, surface, Mesh .....
	* The title of a display should be identical to the menu option used to request that display.	✓Revit Architecture has Tabs and panels. It doesn't include menus and separated toolbars to be matched. 	✓Rhinoceros has menus and floating toolbars. the options in the menus and toolbars are identical. 

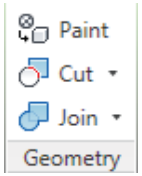
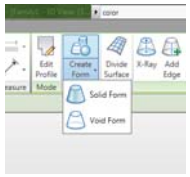
CONSISTENCY		20✓	17.5✓
Is the assignment of color codes conventional?	Color selection: * The harder it is for a user to identify a displayed color, the less useful will be the color code. If many colors are used, colors will be closer in hue and harder to discriminate. If color coding is applied to symbols that subtend small visual angles, which makes color perception difficult, there will be a special need to limit the number of colors used. * If many colors are available, users with normal vision can choose from displayed samples more reliably than from a list of color names.	∞No color selection in mass file in Revit Architecture.	✓Rhino has Select color option. it includes both color code and displayed samples. 
Is the coding consistent across displays, menu options?	Menu: Single Selection per menu: * Each menu display should permit only one selection by the user. Comment. Single-Column List format: * display each option on a new line. *format the list as a single column. Feed back of menu selection: * When a user has selected and entered a control option from a menu, the computer should display some other acknowledgment of that entry. Menu Distinction from other displayed information: * locate menu options consistently in the display and incorporate some consistent distinguishing	∞Revit Architecture has Tabs and panels. It doesn't include menus. ✓*Each tab permit only one selection by the user. ✗*Tabs has multi panels. Each panel includes several icons are displayed in columns and three rows. 	✓Rhinoceros has menus and floating toolbars. ✓*Each menu permit only one selection. ✓*The menus are displayed in one column and each option on a new line. And sub-menus has the same properties too. 

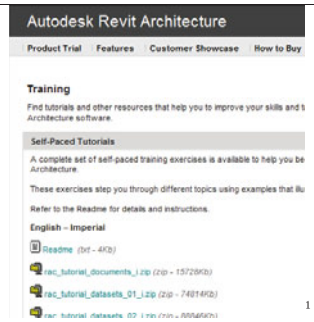
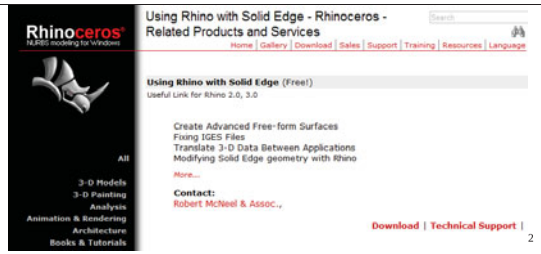
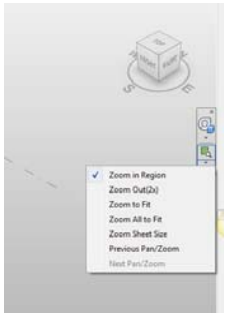
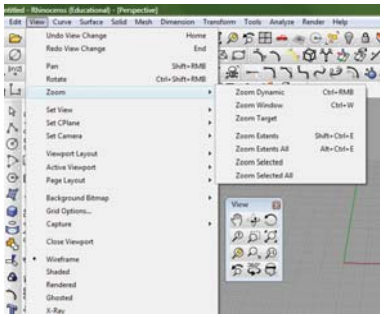
	feature to indicate their special function. General Menu: * Provide a general menu of basic options as the top level in a hierarchic menu structure, a "home base" to which a user can always return as a consistent starting point for control entries. Fast return to General Menu: * users can take only one simple key action to return to the general menu at the top level.	✓ * When user select an icon in the panels, there is information box appears beside the icon and instruction bar at the bottom display acknowledgment of that option.  ✓ * The tabs can be distinguished from the icons and the panels.  ✓ *Revit has main tab called "Home tab". One click on "Home" take user to the top level.	✗ * There is no full explanation of the option when point at it or click on. Only the name of the command appears. In command bar at the bottom, the software provides the user of the steps of the command one by one. But you can't know what the result until the user finish all the steps.   ✓ * The menus can be distinguished from the icons and the toolbars.  ✓ *Rhinoceros has general menu called " File menu". One click on that menu takes the user to the top level. 
Is the display format consistent?	* Data display refers to computer output of data		

Is the label location consistent?	to a user, and assimilation of information from such outputs. http://hcibib.org/sam/2.html		
	* Ensure that whatever data a user needs for any transaction will be available for display.	✔ * The interface of Revit Architecture includes all necessary options and data. 	∞ *Menus in Rhinoceros includes all command of rhino which make it difficult to find the right command. ✘ *The command are available on floating toolbars. If all the toolbars were displayed in the interface by the user. The interface will be crowded and confused. 
	*Tailor displayed data to user needs, providing only necessary and immediately usable data for any transaction; do not overload displays with extraneous data (Display of extraneous data may confuse a user and hinder assimilation of needed information).	✔ *Revit has constant interface, all necessary option are available on the interface. and the interface is not overloaded with extraneous data.	
	* do not make users convert displayed data. Example: If altitude might be required in either meters or feet, then display both values.	✔ *No need for converting the data. The default units in Revit Architecture is feet system. If that system changed to other one, also displayed data will be changed automatically.	✔ *There is consistency between the displayed data and usable data. In addition the display data is consisted with the standards and conventions. and there is no need for converting.
	* Display data consistently with standards and conventions familiar to users. Example: As a negative example, if users work with metric units of measurement, do not display data in English units.		
	* Display titles might be centered at the top of the display, with display identification codes at the upper left corner. The bottom line of the display should be reserved for command entries, where needed, in which case the line just above it could be used for prompts and advisory messages.	✔ * Display titles in Revit Architecture are the upper left corner. ✔ *Instruction bar at the bottom. ✔ *Error messages appear at the bottom right corner of the screen.	✔ * Display titles in Rhinoceros are the upper left corner. ✔ *Command bar at the bottom. ✔ *Error messages appear in the command bar.
	Display Format: * Format refers to the organization of different types of data in a display. * One location might be used consistently for a display title, another area might be reserved for data output by the computer, and other areas dedicated to display of control options,		

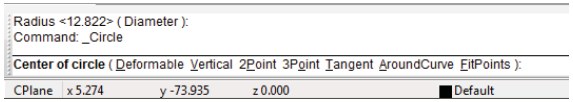
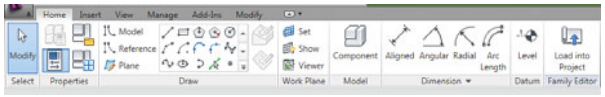
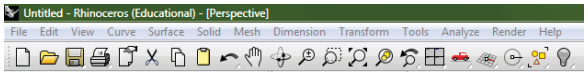
	instructions, error messages, and user command entry.		
Is the label format consistent?	*distinguish different types of labeled material, including consistent differences in display format/placement as well as special fonts and markers.	✓Label format can be distinguished in Revit with the color of the background. Each category such as tab, panel, and icons has different grey colors. Fonts color and size is the same with all commands.	✓Label format can be distinguished easily in Revit because menus are the only labeled in the interface. Floating toolbars are not labeled and distinguished by graphics.
Is the display orientation consistent? -- panning vs. scrolling.	Panning: * Panning will permit users to move continuously over a map in any desired direction, without encountering any internal boundaries imposed by predefined display framing. * In applications where a user can move a cursor freely about a page of displayed data, adopt panning rather than scrolling as the conceptual basis of display framing.	✓Panning option is available in Revit Architecture. ✓*Middle wheel of the mouse can be used for panning by pressing on the wheel, and can be used for Scrolling by scrolling the wheel.	✓Panning is available in Rhinoceros. ✓* Right button is used for panning option in Rhinoceros. While middle wheel is used for scrolling.
Are symbols for graphic data standard?	Icons with similar features have adjacent label and gathered together: * Where displayed curves are too close for direct labeling, an acceptable alternative might be to distinguish the various curves in some way. Icon design Back ground color of icons: * On a light background, a good choice of colors might be red, dark yellow, green, blue and black; on a dark background, good colors might be a somewhat desaturated red, green and blue, plus yellow and white. * Use saturated blue only for background features in a display, and not for critical data. * Saturated blue might be used for shading background areas in graphic displays. * Blue symbols appear dimmer than others, and are more difficult to focus.	∞*Icons with similar features are gathered together in one panel in Revit Architecture. But the labels of these panels are not standard and not present the function of the icons very well.   ✓*Revit Architecture has white background for the icons with blue and black icon's graphic. Red used for deleting, erasing and cutting commands. ✓* Blue used for shading icons which are pointed or clicked.	✓*Icons in Rhinoceros are gathered in the floating toolbars. The floating toolbars can be shown by the user. Right click on the mouse shows the list of all floating toolbars. most of them has short and clear labels.  ✓*Rhino's icons has grey background with blue and black icons. some colorful ions indicate to specific functions as layers, properties and analyzing. ✗*Blue color is used to shade pointed icons only. No specific color for clicked icons which make user is confused about the icon that he/she selected.

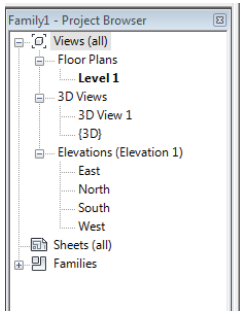
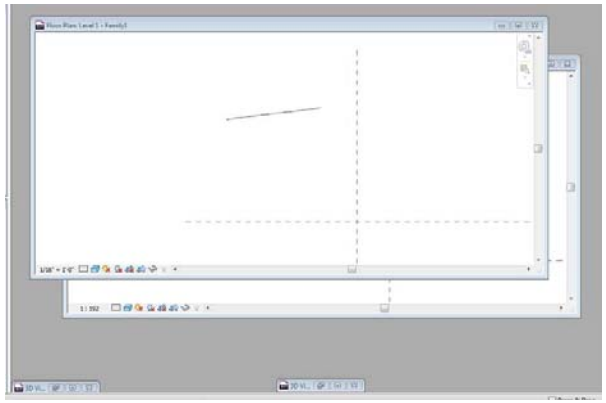
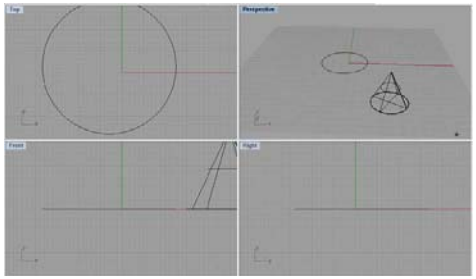
	Icon labels: * The display identification label should be unique, short, but meaningful enough to be remembered easily. * The label does not take the place of a full, descriptive title. The full title would be displayed separately. * Place the identifying label used for display selection in a prominent and consistent location on each display. The top left comer of the display might be used for this purpose. Iconic Menus: * providing graphic menus which display icons to represent the control options.	 ∞ *Revit includes short and long label for its icons. the shortest one are clearer than the long ones which they are complicated and ambiguis.  ✓ * Revit includes a descriptive tiltes which they are appear only when pointing or clicking on the icons. ✓ *all icons and labels are displayed at the upper left corner of the display. ✓ * Revit includes iconic panels.	 ✗ *The icons are not labeled. The labels only appears when pointing on the icon.  ✗ *There is no descriptive titles for the commands and icons in Revit. ✓ *All icons and labels are displayed et the upper left corner of the interface. ✓ *Revit includes iconic floating toolbars.
FLEXIBILITY		**8.5**✓	**9.5**✓
Does it have direct manipulation capability?	Direct Manipulation capability: * An example of direct-manipulation is resizing a graphical shape, such as a rectangle, by dragging its corners or edges with a mouse. http://en.wikipedia.org/wiki/Direct_manipulation_interface	✓ *Revit has direct manipulation capability. 	✓ *Rhino has direct manipulation capability. 
Can the display be controlled by user flexibly?		✗ *Revit 's display can't be controlled. it has fixed display and can't be customized.	✓ *Rhino's display can be customized and controlled.

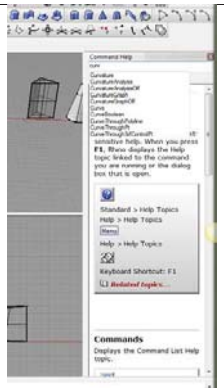
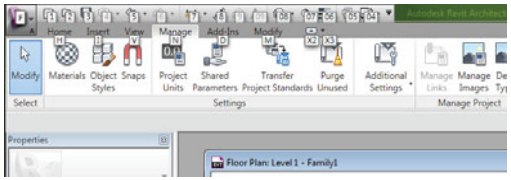
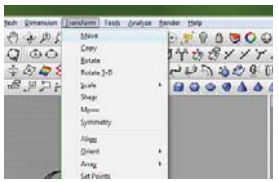
Does it provide flexible sequence control?	Sequence Control: * Sequence control refers to user actions and computer logic that initiate, interrupt, or terminate transactions. Sequence control governs the transition from one transaction to the next. Minimal User Action: * control logic should permit completion of a transaction sequence with the minimum number of actions consistent with user abilities. Example: control logic should permit completion of a transaction sequence with the minimum number of actions consistent with user abilities. Control Matched to User Skill: * Permitting simple step-by-step actions by beginners, but permitting more complex command entry by experienced users. Congruent Names of Control Functions: * If one function name is UP, then DOWN (rather than LOWER, say) should accomplish an opposite function; PULL should be reversed by PUSH; FORWARD by BACKWARD; RIGHT by LEFT; IN by OUT; etc. Compatibility with User Expectations: * Ensure that the results of any control entry are compatible with user expectations.	∞ *some of sequence control in Revit need small number of actions and others need big number. that depends on the command. ✓ *Beginners in Revit can work step by step following the instructions in the bottom bar of the display. It also include API for experts to script more complex commands. ✓ *Revit includes some congruent names of control functions such as Cut & Join, and Form& Void.   ✓ *Most of command are compatible with user's expectations.	∞ *some of sequence control in Rhinoceros need small number of actions and others need big number. that depends on the command. ✓ *Beginners in rhinoceros can work step by step following the instructions in the bottom bar of the display. It also include additional attached applications for experts to script more complex commands such as Monkey and Grasshopper. ✗ *No congruent names. ✓ *Most of commands are compatible with user's expectations.
Does it provide good training for different users?	On-Line training: * provide an on-line training capability to introduce new users to system capabilities	✓ *Autodesk provide users with free online documents for Training.	✓ *Rhinoceros website provide online training documents.

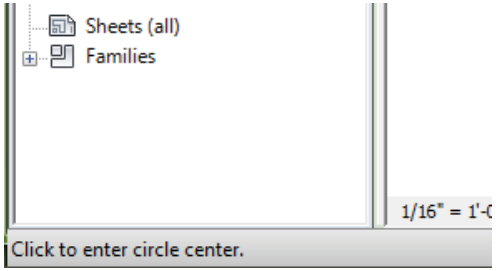
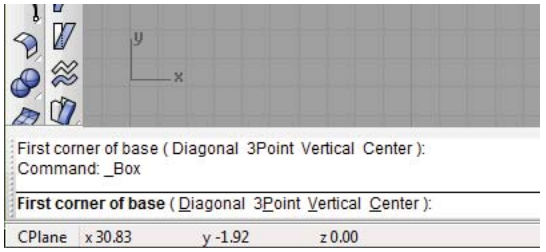
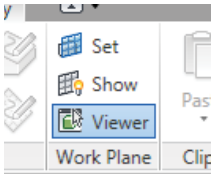
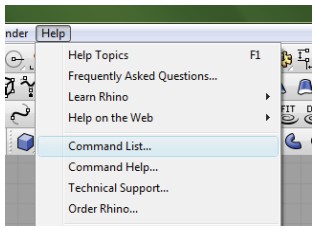
		 [1]	 [2]
Are users allowed to customize windows?		✘*Revit 's display can't be controlled. it has fixed display and can't be customized.	✓*Rhino's display can be customized and controlled.
Does it provide zooming for display expansion?	Zooming: *Zooming capabilities.	✓*Middle wheel of the mouse can be used for zooming by scrolling the wheel. ✓*Shift+alt + Middle button/Right button of the mouse. ✓*Right side of Revit screen provide the user with zooming options.  	✓*Middle wheel of the mouse can be used for zooming by scrolling the wheel. ✓* Right button of the mouse. *View menu>Zoom (Provide zooming options). ✓*Right click provide the user with floating toolbar View which includes all zooming options. 

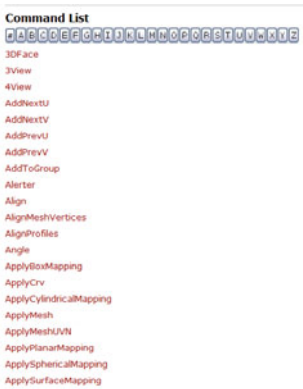
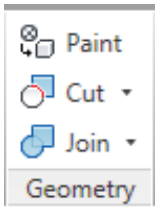
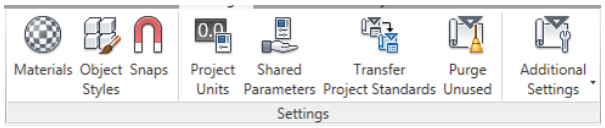
[1] Autodesk, "Training," 2011, http://usa.autodesk.com/revit-architecture/training/?preview=1
[2] Rhinoceros, "*Using Rhino with Autodesk Inventor - Rhinoceros - Related Products and Services*," 2011, http://www.rhino3d.com/resources/display.asp?language=en&listing=469

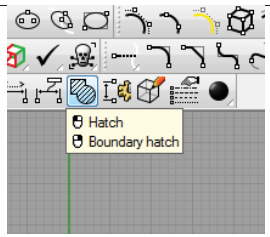
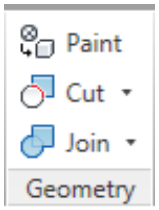
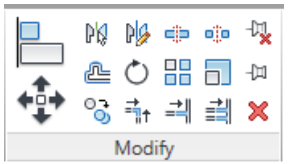
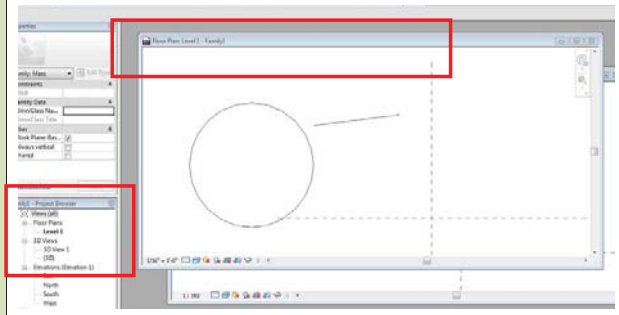
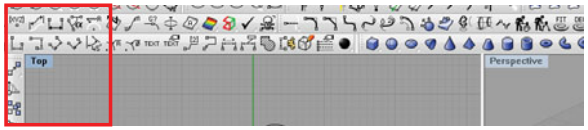
LEARNABILITY		**0.5**✓	**3**✓
Is the command language layered?		✗No command language.	✓The command language is layered. 
Is the grouping of menu options logical? Is the ordering of menu options logical?		∞*The grouping of tabs options are logical, but the panels are not clear and not logical. 	✓*The grouping and ordering of menus options are logical. 
Are the command names meaningful?	Availability of Command Language: * Command-language dialogues for tasks involving a wide range of control entries, where users may be highly trained and will use the system frequently. Location of Command bar: * command entry area should be in a consistent location on every display, preferably at the bottom. Command's familiar wording: * Choose command names that are meaningful. * To transfer a file, the assigned command should be something like TRANSFER, MOVE, or SEND.	✗No command language.	✓*The command language is available, it's located at the bottom of the interface. *All the options in the menus can be used in the command bar.
MINIMAL ACTION		**5.5**✓	**6**✓
Does it provide default values?	Default Values: * default values can be defined for the data entries in a particular task, offer those default values to speed data entry.	∞*Mass file in Revit Architecture doesn't include options need default values. Default values can be found in components and annotations options.	✓*Rhinoceros has default values in most of its options and commands.
Is the shifting among windows easy?	Easy Shifting among Windows: * If several window overlays are displayed at	✓*The shifting process among different views in the same file is easy. It can be	✓*The shifting process in Revit is easy and flexible. It provides the user with a

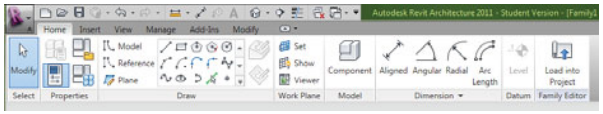
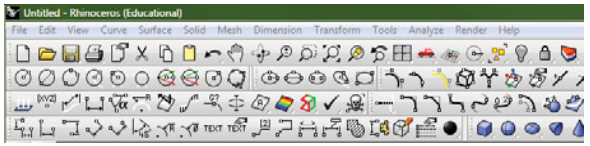
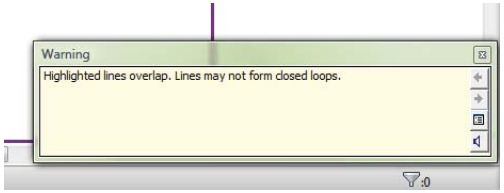
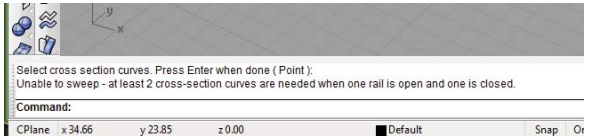
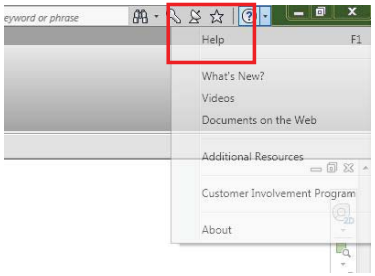
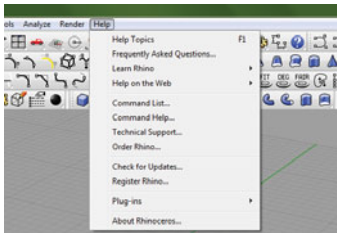
	once, provide some easy means for a user to shift among them to select which window shall be currently active.	done using Project Browser dialogue in the left side of the display.  ✘*The problem that the shifting process between files is difficult. The user can't know which windows belong to specific file, and the opened files are not visible to the user until he/she minimizes the windows. 	screen is divided to four different views. The user can click on the title of one of them to maximize it.  ✘*Rhino can't open more than one file in the software. To open other file, another Rhinoceros will be launched or close the current file to open another one.
Does it provide global search and replace capability?		✓Revit provides global search.  	✓*Provides command search.

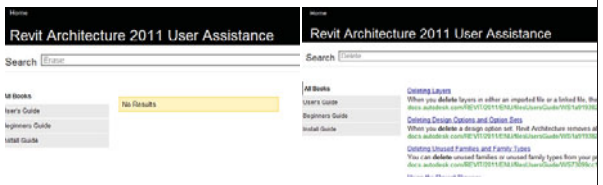
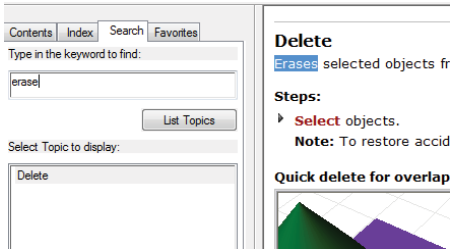
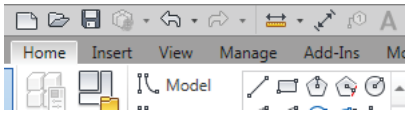
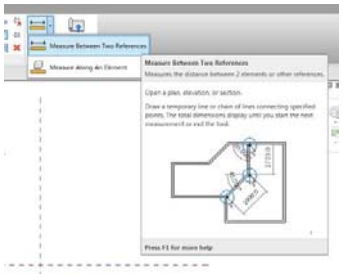
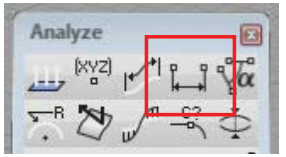
			
Is the menu selection by pointing? -- primary means of sequence control.		✓ * Yes.	✓ *Yes.
Is the menu selection by keyed entry? -- secondary means of control entry.		✓ *Revit can be controlled by keyed entry. Pressing alt key will provide the user the ability to control Revit using keyboard. 	✓ *Rhinoceros can be controlled by keyed entry. Pressing alt key will provide the user the ability to control Rhino using keyboard. In addition, Each option in the menus and icons are provided with a key shortcut. 
Is the return to general menu required only one simple key action?		✓ Yes.	✓ Yes.
MINIMAL MEMORY LOAD		5✓	5✓
Is the guidance information always available?	Consistent Format of User Guidance: * Display titles might be centered at the top of the display, with display identification codes at the upper left corner. The bottom line of the display should be reserved for command entries, where needed, in which case the line just above it could be used for prompts and advisory messages. Speaking directly to users: * Choose wording for user guidance that speaks	✓ * Display titles in Revit Architecture are the upper left corner. ✓ *Instruction bar at the bottom. ✓ *Error messages appear at the bottom right corner of the screen. ✓ *User guidance is available and speaks directly to the user.	✓ * Display titles in Rhinoceros are the upper left corner. ✓ *Command bar at the bottom. ✓ *Error messages appear in the command bar. ✓ *The user guidance in Rhino is presented in the command bar which is always available and speaks directly to the user.

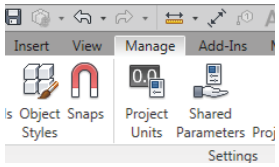
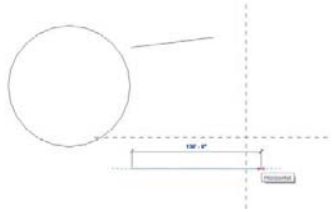
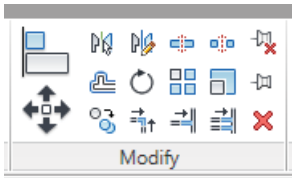
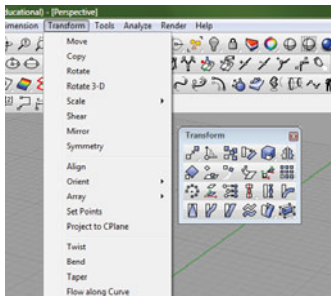
	directly to a user, rather than talking about users. Example (Good) | Press ENTER to continue. | (Bad) | The user should press ENTER to continue. | Guidance information always available: *Do not require a user to remember information not currently displayed. The user should not have to remember what actions are available, or what action to take next. Human memory is unreliable, and without guidance users can be expected to make errors.		
Are selected data highlighted?	High light graphic displays are provided: Example: On a bar chart, one bar representing an out-of-tolerance condition might be textured or shaded differently to call attention to it and to contrast it with other bars. * This practice will help avoid error, if a user has misunderstood or perhaps forgotten which item was selected.	✓ * Blue used for shading icons which are pointed or clicked. 	✘ *Blue color is used to shade pointed icons only. No specific color for clicked icons which make user is confused about the icon that he/she selected. 
Does it provide index of commands?	Index of Commands: * Such a command index may help a user to phrase a particular command, and will also be generally helpful as a reference for discovering related commands and learning the overall command language.	✘ No index of Commands.	✓ *Rhino provides Command List. It can be entered by clicking on Help>Command List... 

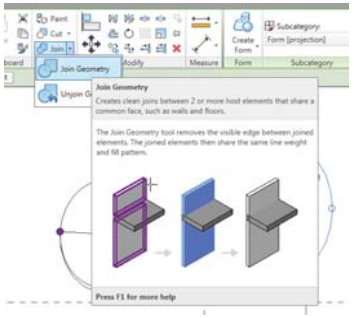
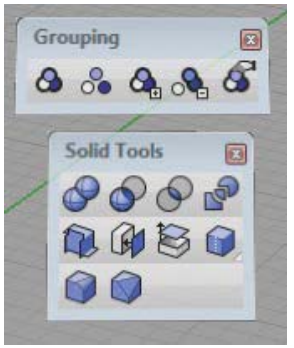
			
PERCEPTUAL LIMITATION		**4.5**✓	**4**✓
Is the spelling distinctive for commands?		✗*The labels of these panels are not standard and not present the function of the icons very well.  ∞*Revit includes short and long label for its icons. the shortest one are clearer than the long ones which they are complicated and ambiguous. 	✓*Most of menus options, icons and commands in Rhinoceros has short and clear labels. ✗*The icons are not labeled. The labels only appears when pointing on the icon.

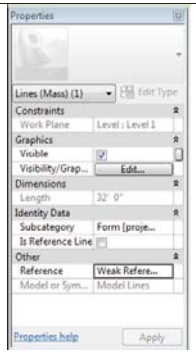
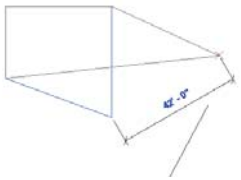
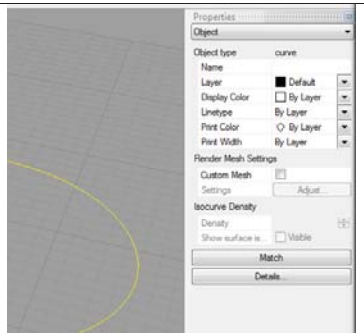
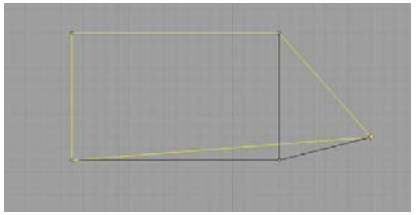
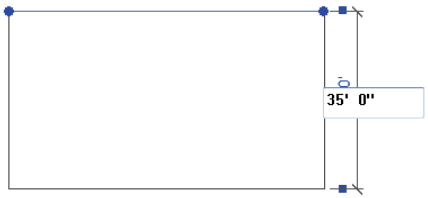
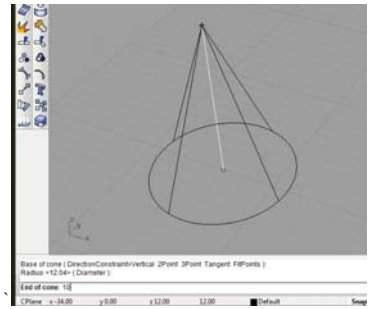
		✓ * Revit includes a descriptive tiltes which they are appear only when pointing or clicking on the icons.	 ✗ *There is no descriptive titles for the commands and icons in Revit.
Does it provide easily distinguished colours?		✓ *Yes, Revit Architecture has white background for the icons with blue and black icon's graphic. Red used for deleting, erasing and cutting commands.  	✓ *Rhino's icons has grey background with blue and black icons. some colorful ions indicate to specific functions as layers, properties and analyzing. 
Is the active window indicated?		✓ Yes. They are activated with blue bar and bold font in Project Browser. 	✓ Yes. They are activated with blue bar. 
Are menus distinct from other displayed information?		✓ Label format can be distinguished in Revit with the color of the background.	✓ Label format can be distinguished easily in Revit because menus are the only

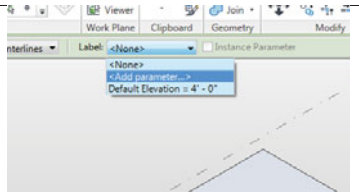
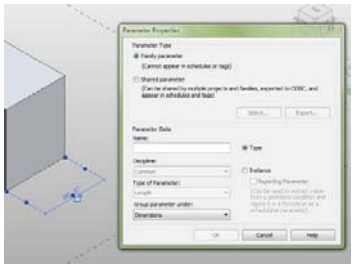
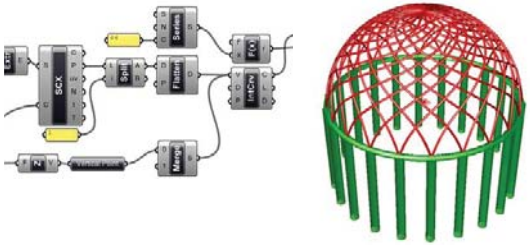
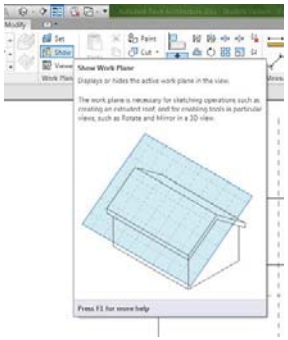
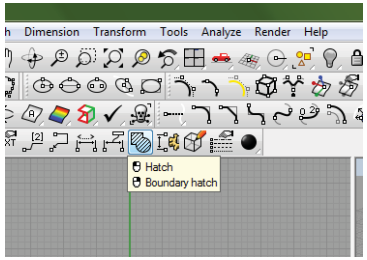
		Each category such as tab, panel, and icons has different grey colors. Fonts color and size is the same with all commands. 	labeled in the interface. Floating toolbars are not labeled and distinguished by graphics. 
USER GUIDANCE		**3.5**✓	**5**✓
System feedback: How helpful is the error message?	Error Messages: * Error messages help prevent user errors and correct those errors that do occur. * If a user selects a function key that is invalid for a particular transaction, no action should result except display of an advisory message indicating what functions are appropriate at that point. * When the computer detects an entry error, display an error message to the user stating what is wrong and what can be done about it.	∞*Revit provides Error messages in the right bottom corner of the display. The messages are not useful sometimes and doesn't provide the solution of the error or the mistake. It sometimes make the user more confused. 	✓*Rhino provides error messages in the command bars. They are helpful. They provide the solution of the error or the mistake. 
Does it provide CANCEL option?	Cancel option: * CANCEL option have the effect of erasing any changes just made by the user and restoring the current display to its previous version.	✓*Escape key cancels any ongoing process in Revit.	✓*Escape key cancels any ongoing process in Revit.
Is HELP provided?	Help: Manual Help: On-Line help: * Permit users to obtain further on-line guidance by requesting HELP. Synonyms of Standard Terminology: * When a user requests HELP on a particular topic, the computer should accept synonyms for standard system terminology. Example: If a	✓*Revit provides on-line help. 	✓*Rhino provides help documents and online help.  ✓*Rhinoceros' help accept synonyms of Standard terminology.

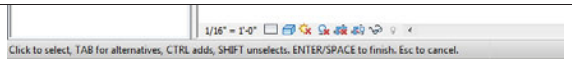
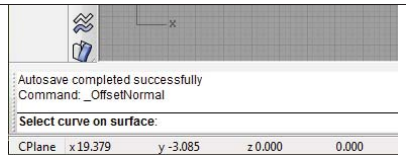
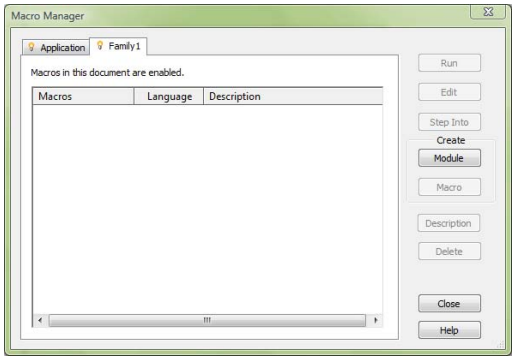
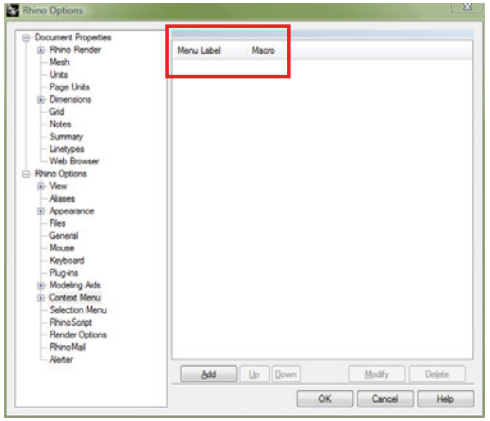
	DELETE command exists, then an explanation of that command might be displayed when a user requests HELP for ERASE.	✘*Revit' help doesn't accept synonyms of Standard terminology. 	
Does it provide UNDO to reverse control actions?	Undo option: * Ensure that any user action can be immediately reversed by an UNDO command.	✓*Yes. 	✓*Yes. 
Other Options		**13.5**✓	**13**✓
	Distance option. Snapping points: * An effective computer logic to aid line connection is to provide a so-called "gravity field" surrounding each line segment, so that if a line-drawing cursor is moved within that field the cursor's new line will be extended automatically to intersect the already-displayed line. Ortho feature: When graphic elements are created with vertical and horizontal lines, allow users to specify appropriate constraints during line drawing. Resize(Scale) option:	✓*Distance option is provided by Revit.  ✓*Revit provides snapping option. It's called Snaps.	✓*Distance option is provided in Rhinoceros.  ✓*Rhinoceros provides snapping and ✓Ortho options.

	* When editing graphic data, allow users to change the size of any selected element on the display. Copy option: * Allow users to copy a selected graphic element in order to duplicate it elsewhere or create a repeating pattern. Comment Rotate option: * When editing graphic data that depict objects, allow users to rotate a selected element on the display, in order to show it in different orientations. Mirror option: * When users must create symmetric graphic elements, provide a means for specifying a reflection (mirror image) of existing elements. Group option: * Allow users to designate a group of elements to which graphic editing operations will be applied in common. Boolean option: * In the special case when a drawn object can be created by the junction or disjunction of other graphic elements, provide computer aids for merging those elements by boolean combination.	  ✓*Revit provides Ortho option.  ✓*Scale, Copy, Rotate and Mirror options are provided by Revit in Modify tab>Modify panel.  	  ✓*Scale, Copy, Rotate, and Mirror options are provided by Rhinoceros. 

		∞ *In Mass file in Revit, there is no Group option. Model Group option only available in PF. ✓ *Join Geometry option presents Boolean operation in Revit MMF. 	✓ *Group and ✓ Boolean operations are provided in Rhinoceros. 
	Fast Response to commands: * Ensure that the computer will acknowledge data entry actions rapidly. Delays in displayed feedback should not exceed 0.2 seconds. * Computer response to a likely control entry, such as NEXT PAGE, should be within 0.5-1.0 second; response to other simple entries should be within 2.0 seconds; error messages should be displayed within 2-4 seconds.	✓ Yes.	✓ Yes.
	Changing Attributes: * When entering or editing graphic data, allow users to change display attributes -- e.g., line type, cross-hatching, color -- for selected graphic elements. Rubber banding feature: * This technique permits users to enter or change a line segment rapidly and with confidence by designating its starting point and then simply	✓ *Revit provides a property dialogue for selected objects.	✓ *Rhino provides with Properties dialogue for selected objects.

	moving the cursor to the desired end-point. *.A rectangle might be rubberbanded by fixing one corner and moving the opposite corner. A circle might be rubberbanded to desired size by fixing its center and changing the extension of its radius.	 ✓*Revit include Rubber banding feature. 	 ✓*Rhino has Rubber banding feature. 
	Parametric option: * allow users to create particular instances by entering appropriate parameters.	✓*Revit has the ability to change the parameters of any shape or geometry.  ✓*Revit has the ability to create parametric form.	✓*Rhino has the ability to enter the parameters of any shape or geometry.  ✓*Rhinoceros has some plug-ings tha supprot it to craete parametric forms such as Grasshopper applications.

		 	
	Function Keys for Frequent Control Entries: * Commonly used function keys include ENTER, PRINT, NEXT PAGE, PREV PAGE, OPTIONS, etc. *They need not be included in displayed menus.	✓ *functions keys for frequent control entries are used in Revit.	✓ *functions keys for frequent control entries are used in Rhino.
	Graphic guidance and explanation of icons: * A guidance display providing a graphic representation of keypad layout with notes explaining the various key functions might help a novice user to learn the control options available via function keys.	✓ * Yes. Revit includes graphic guidance and explanation of icons. When the user select an icon in the panels, there is information box appears beside the icon and instruction bar at the bottom display acknowledgment of that option. 	✗ * There is no full explanation of the option when point at it or click on. Only the name of the command appears. In command bar at the bottom, the software provides the user of the steps of the command one by one. But you can't know what the result until the user finish all the steps. 

			
	Macro option: * Allowing users to assign a single name to a defined series of control entries, and then use that named "macro" for subsequent command entry.	✔*Yes, it includes Macro option in Macros panel in Manage tab.  	✔*Yes, it includes Macro option in Tools>Options. 

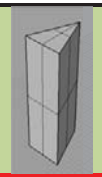
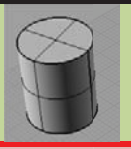
Appendix E

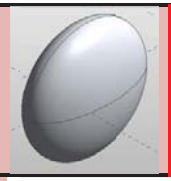
The Results of the Main Method

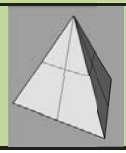
Solids:

a. Preliminary solids:

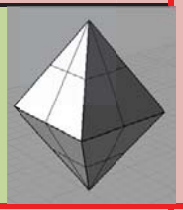
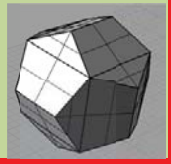
Comparison Factor *Software*	*Date*	*Time* *1st Time*	*2nd Time*	*Clicks*	*Steps*	*Difficulties*	*Variables*	*Notes*	*Comparison Factor* *Geometries*	*Result*
Revit Architecture	26.10.2010		00:00:53 ✔	37	**14**		- Good Mood - Optimistic	**Second Time**	***Sphere*** 	
Rhino	09.11.2010		00:00:43 ✔	23	**7**		- Good Mood - Optimistic	Default Parametric Sphere		
Revit Architecture	04.12.2010 18.02.2011	00:01:30 ✔	00:02:22 ✔	47 136	**17**		-Tired (Bad mood) - Optimistic	**Second Time** **Successful experiment**	***Cone*** 	
Rhino	09.11.2010		00:00:10 ✔	15	**7**		- Good Mood - Optimistic	*Default Parametric Cone. **Successful experiment**		
Revit Architecture	26.10.2010	00:01:16 ✔			**14**			MM	***Prism***	
	11.11.2010		00:00:42 ✔	34			- Good Mood - Optimistic	MM **Second Time** **Successful experiment**		

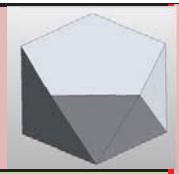
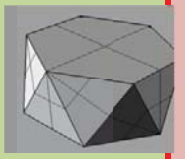
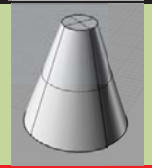
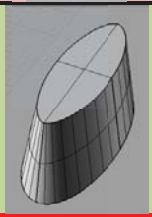
Rhino	09.11.2010	00:00:20	00:00:19 ✔	28	9		- Good Mood - Optimistic	Successful experiment	
Revit Architecture	27.9.2010	00:35:00 ✕				* No 3D snapping, make it difficult to snap vertical line to the horizontal ones.		GM	***Pyramid*** 
	27.9.2010	01:17:00 ✔			26	* Only could create facet Pyramid ...no: volume one.		MM - Facet Pyramid - 3D snapping option	
	04.02.2011 18.02.2011	00:40:44 ✔	00:10:46 ✔	682	61		-Tired (Bad mood) - Optimistic	Three tries to achieve a successful experiment. **Second Time**	
Rhino	09.11.2010		00:00:11 ✔	15	9		- Good Mood - Optimistic	- One Successful Experiment. **Second Time**	
Revit Architecture	26.10.2010		0:00:24 ✔	21	14		- Good Mood - Optimistic	MM **Second Time** Successful experiment	***Cylinder*** 
Rhino	09.11.2010		00:00:17 ✔	11	7		- Good Mood - Optimistic	**Second Time** Successful experiment	
Revit Architecture	19.9.2010	00:17:00 ✕							***Ellipsoid***
	15.11.2010	00:01:10 ✕							

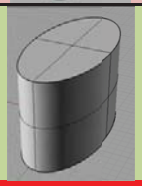
	15.11.2010	00:07:19 ✔		253				MM	
	15.11.2010	00:02:54 ✔	00:01:09 ✔	118 43		*The problem of Generic Model that it should be loaded to Mass. File then to Project. File to work on it. If it load directly to Project. File then it can be considered there as Generic model family not as a Mass. Therefore, Floors can't be added to the geometry.		GM	
	15.11.2010	00:03:29 ✘							
	15.11.2010 18.02.2011	00:00:32 ✔	00:01:35 ✔	22 112	**15**		-Tired (Bad mood) - Optimistic	MM **Six tries to achieve a successful experiment.** **Second Time**	
Rhino	09.11.2010		00:00:13 ✔	11	**8**		- Good Mood - Optimistic	*Default Parametric Cone. **-One try to achieve a successful experiment.** **-Second Time**	
Revit Architecture	06.02.2011 18.02.2011	00:02:09 ✔	00:01:09 ✔	114 120	**24**		-Tired (Bad mood) - Optimistic	**-Second Time** **Successful experiment**	***Torus*** 
Rhino	09.11.2010		00:00:06 ✔	10	**7**		- Good Mood - Optimistic	**-Second Time** **Successful experiment**	
Revit Architecture	28.10.2010	00:11:04 ✘				*Prism Deformation and NURBS operations.		MM	***Tetrahedron***

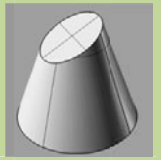
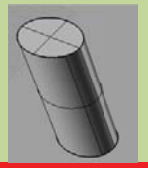
										
		00:20:37 ✔	00:11:25 ✔			*That is tetrahedron with surfaces doesn't work to create floor plans inside it.		MM Surface Tetrahedron		
	02.11.2010	00:36:54 ✖				*Try create Tetrahedron with subtracting 3 triangular prism of main triangular prism. *You have to set Work plane for each step which has difficulties to set it.		MM		
	02.11.2010	00:44:56 ✖				*Try to subtract 3 pyramids from triangular prism.		MM		
	02.11.2010	00:08:26 ✖				*Try to create Tetra using lines and create form.		MM		
	02.11.2010	00:30:03 ✖				*Try to use Forms operation (Revolve).		GM		
	02.11.2010	00:29:54 ✖				*Revolve profile around triangular prism.		MM		
	03.11.2010	00:20:34 ✖				*subtract Prism again.		MM		
	03.11.2010	00:05:20 ✖				*Use Add Edge option and NURBS operation.		MM		
	03.11.2010	00:15:38 ✔		843	**44**	*Dividing the tetrahedron to three connected pyramids. *I wasted a lot of time in repeating the same steps in creating each geometry instead of creating one and copy it to other two copies and connect them.	**- Discomfort (Bad Mood)** **- Pessimistic**	MM **-Ten tries to achieve a successful experiment.** **-FirstTime** **-Successful experiment**		
Rhino	09.11.2010	00:06:59 ✔						*Different way of creating > long method.		
	06.12.2010	00:02:22 ✔		135	**19**		**- Tired (Bad Mood)** **- Optimistic**	*Default Parametric **-Two successful tries.** **-FirstTime** **-Successful experiment**		

b. Secondary Solids:

Comparison Factor / *Software*	*Date*	*Time* 1st Time	*Time* 2nd Time	*Clicks*	*Steps*	*Difficulties*	*Variables*	*Notes*	*Comparison Factor* / *Geometries*	*Result*
Revit Architecture	04.02.2011	00:40:44 Create two pyramids. 00:42:19 ✕ Create octahedron by connecting the two pyramids		**1640** ---		*Void solids appear when two geometries have void solids are connected to each other which make the final geometry looks bad.	- Tired (Bad Mood) - Optimistic because I created Pyramids before, and thought that will work.	-Two tries -Failed experiment because of Void problem.	***Octahedron***	↑
Rhino	16.11.2010	00:09:24 ✔		**362**	**29**		- Good Mood - Optimistic	-Successful experiment		
Revit Architecture	03.11.2010	00:26:29 ✕				*Used Sphere with dividing its surface, but cculdn't find pentagonal system. *Try to create the pentagonal system by creating new curtain panel.			***Dodecahedron***	↑
	03.11.2010	01:00:41 ✕				*Try dividing the dodecahedron to many small pyramids and connect them to bigger pyramids to connect them which will create dodecahedron.				
	08.11.2010	01:17:40 ✕				*Start with cube and adding pyramids to different faces of the cube.	- Good Mood - Optimistic	-Three tries -Failed experiment.		
Rhino	16.11.2010	00:14:10		**727**	**15**		- Good Mood - Optimistic	-Successful experiment -First time.		
Revit Architecture	08.11.2010	02:01:07 ✕				* Connecting two hexagon with Create Form command. *NURBS operations for Prism. *Dividing Anti-Prism to small pyramids *Subtracting pyramids from Prism by using Void forms.			***Anti-Prism***	
	01.02.2011	00:40:02 ✕								

	01.02.2011 18.02.2011	00:31:43 ✔	00:20:15 ✔	1382 1429	57	*To Draw a polygon in Revit with specific side length, you should know the diameter first which need calculations and take time. *All the sides of Anti prism has same length, therefore you should calculate the height of Ant-prism to achieve that.	- Tired (Bad Mood) - Optimistic.	-Three tries to achieve a successful experiment -Second try -Successful experiment.	
Rhino	16.11.2011	00:08:57 ✔	00:13:08 ✔ Create Anti-prism with equilateral triangles faces.	348 601	36		- Good Mood - Optimistic	-Second try. -Successful experiment.	
Revit Architecture	19.9.2010	00:14:00 ✔			25			MM	*Truncated Cone*
	27.10.2010		00:02:00 ✔	95			- Good Mood - Optimistic	MM -Second try -Successful experiment.	
Rhino	09.11.2010		00:00:06 ✔	15	7		- Good Mood - Optimistic	-Second try. -Successful experiment.	
Revit Architecture	19.9.2010 18.02.2011	00:11:00	00:02:03 ✔	--- 163	33		- Good Mood - Optimistic.	MM -Second try -Successful experiment.	*Semi. Elliptical Cone* 
Rhino	09.11.2010		00:03:42 ✔	184	13		- Good Mood - Optimistic.	-Second try -Successful experiment.	
Revit	26.10.2010		00:00:40		5			MM -Second try	*Elliptical*

Architecture								-Successful experiment.	*Cylinder* 	
Rhino	09.11.2010		00:00:40 ✔	**63**	**14**			-Second try -Successful experiment.		
Revit Architecture	20.9.2010 18.02.2011	00:44:00 ✘ 00:42:00 ✔	00:03:40 ✔	**347**	**22**	* 22 steps is the minimum steps, the steps can be more due to placing process. * After Cut Geometry process, if we select the Oblique Cone, the void geometry will appear in x ray mode. That's mean that the void geometry will be always connected to the resulted geometry and if deleted the original geometry will appear again.	- Tired (Bad Mood) - Optimistic.	GM MM -Second try -Successful experiment.	*Oblique Circular Cone* 	
Rhino	09.11.2010		00:04:33 ✔	**206**	**25**		- Good Mood - Optimistic.	-Second try -Successful experiment.		
Revit Architecture	19.9.2010 18.02.2011 19.02.2011	02:11:00 00:01:53 ✔	00:02:20 ✔	**186** **201**	**28**	* Create levels only work in elevations or sections. * Difficulties with creating work plane, it takes long time to create it. *Cutting the geometry without change it to void, doesn't work, because it will still appear and connect with the other geometry, and if deleted it the cut geometry process will be cancelled. *Boolean operations in Revit only limited in Join and Cut.	- Tired (Bad Mood) - Optimistic.	MM -Second try -Successful experiment.	*Right Circular Cone* 	

Rhino	09.11.2010		00:04:33 ✔	**206**	**25**		- Good Mood - Optimistic.	-Second try -Successful experiment.		
Revit Architecture	26.10.2010 18.02.2011		00:01:40 00:00:50 ✔	**67**	**21**		- Tired (Bad Mood) - Optimistic.	MM -Second try -Successful experiment.	***Oblique Circular cylinder*** 	
Rhino	09.11.2010		00:02:11 ✔	**141**	**17**		- Good Mood - Optimistic.	-Second try -Successful experiment.		

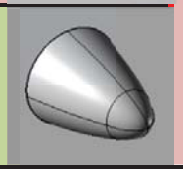
c. Complex Solids:

Comparison Factor / *Software*	*Date*	*Time* 1st Time	*Time* 2nd Time	*Clicks*	*Steps*	*Difficulties*	*Variables*	*Notes*	*Comparison Factor* / *Geometries*	*Results*
Revit Architecture	01.02.2011	00:31:43 ✔ Create Anti-Prism. 00:21:04 ✘ Create two pyramids and connect them to Anti-Prism geometry.				*Void solids appear when two geometries have void solids are connected to each other which make the final geometry looks bad.	- Tired (Bad Mood) - Optimistic because I created Pyramids before, and thought that will work.	-One try -Failed experiment because of Void problem.	*Icosahedron*	
Rhino	16.11.2010	00:09:05 ✔ Create Anti-Prism. 00:14:21 ✔ Create two pyramids and connect them to Anti-Prism geometry.		**526** **682**	*Create Anti-Prism:* **32** *Create Icosahedron:* **34**		- Tired (Bad Mood) - Optimistic.	-One try -Successful experiment.		

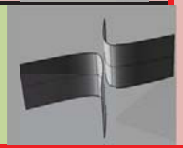
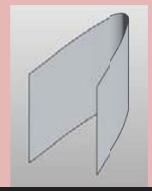
Surfaces:

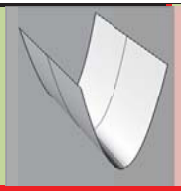
a. Preliminary Surfaces:

Comparison Factor: Software	Date	Time: 1st Time	Time: 2nd Time	Clicks	Steps	Difficulties	Variables	Notes	Comparison Factor: Geometries	Results
Revit Architecture	15.11.2010	00:43:40 ✔		1912	*Creating Hyperbola curves:* 25	*There is a lot of calculation operations which takes time. *I look tired in that experiment and did a lot of calculation mistakes that is why it took long time to work.		MM	***One Sheet Hyperboloid***	
	15.11.2010	00:15:04 ✔		526	6		- Good Mood - Optimistic.	MM **-Successful experiment.**		
Rhino	03.02.2011	00:14:14		114	35		- Tired (Bad Mood) - Optimistic.	**-Successful experiment.**		
Revit Architecture	15.11.2010	00:06:36 ✔		474	**Create hyperbola curves.* 25 7		- Good Mood - Optimistic.	**-Successful experiment.**	***Two Sheets Hyperboloid***	
Rhino	03.02.2011	00:10:19		140	32		- Tired (Bad Mood) - Optimistic.	**-Successful experiment.**		
Revit Architecture	02.02.2011	00:10:29 ✔ Create Parabola curve 00:05:30 ✔ Create Paraboloid		317 226	*Create Parabola curve:* 18 *Create Paraboloid:* 8		- Tired (Bad Mood) - Optimistic.	**-First time.** **-Successful experiment.**	***Paraboloid***	

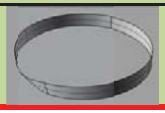
										
Rhino	09.11.2010	00:00:12 ✔		22	7		- Good Mood - Optimistic.	-First time. -Successful experiment.		

b. Secondary Surfaces:

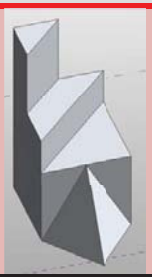
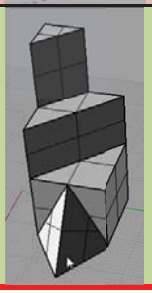
Comparison Factor **Software**	*Date*	*Time* 1st Time	*Time* 2nd Time	*Clicks*	*Steps*	*Difficulties*	*Variables*	*Notes*	*Comparison Factor* Geometries	*Results*
Revit Architecture	15.11.2010	00:07:14 ✔		571	**Create hyperbola curve.* 25 2		- Good Mood - Optimistic.	-First time. -Successful experiment.	*Hyperbolic Cylinder* 	
Rhino	03.02.2011	00:02:58 Create Hyperbola curve ✔ 00:01:04 Create Hyperbola Cylinder ✔		57 28	12		- Tired (Bad Mood) - Optimistic.	-First time. -Successful experiment.		
Revit Architecture	02.02.2011	00:10:29 ✔ Create Parabola curve 00:00:11 ✔ Create Parabolic Cylinder		317 6	*Create Parabola curve.* 18 *Create Paraboloid Cylinder:* 3		- Tired (Bad Mood) - Optimistic.	-First time. -Successful experiment.	*Parabolic Cylinder* 	

Rhino	03.02.2011	00:00:27 ✔ Create Parabola curve 00:01:59 ✔ Create Paraboloid Cylinder		7 90	19		- Tired (Bad Mood) - Optimistic.	-First time. -Successful experiment.		
Revit Architecture	02.02.2011	00:10:29 ✔ Create Parabola curve 00:13:28 ✔ Create Elliptic Paraboloid.		599	*Create Parabola curve.* 18 *Create Elliptic Paraboloid:* 20	*Ellipse can be drawn only by specify the center, there is no other option to draw it by specify its diameter first.	- Tired (Bad Mood) - Optimistic.	-First time. -Successful experiment.	*Elliptic Paraboloid* 	
Rhino	03.02.2011	00:00:27 ✔ Create Parabola curve 00:12:27 ✔ Create Elliptic Paraboloid		7 401	33		- Tired (Bad Mood) - Optimistic.	-First time. -Successful experiment.		

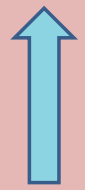
c. Complex Surfaces:

Comparison Factor / *Software*	*Date*	*Time* 1st Time	*Time* 2nd Time	*Clicks*	*Steps*	*Difficulties*	*Variables*	*Notes*	*Comparison Factor* / *Geometries*	*Results*
Revit Architecture	18.02.2011		00:21:14 ✔	1629	33		- Tired (Bad Mood) - Optimistic.	-Second time. -Successful experiment.	*Mobuis Strip* 	
Rhino	03.02.2011	00:31:58 ✘								
	03.02.2011 18.02.2011	00:05:19 ✔	00:07:27 ✔	605	34		- Tired (Bad Mood) - Optimistic.	-Two tries to achieve successful experiment. -Second time. -Successful experiment.		

Configuration & Transformation Stage:

Comparison Factor / Software	Date	Time 1st Time	Time 2nd Time	Clicks	Steps	Difficulties	Variables	Notes	Comparison Factor / Geometries	Results
Revit Architecture	18.02.2011	00:18:32 ✔		1104			- Tired (Bad Mood) - Optimistic.	-First time. -Successful experiment.		
Rhino	18.02.2011	00:10:04 ✔		677			- Tired (Bad Mood) - Optimistic.	-First time. -Successful experiment.		

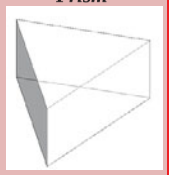
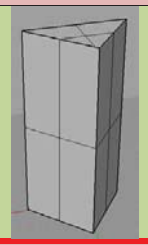
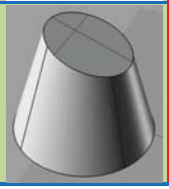
Load & Export Process:

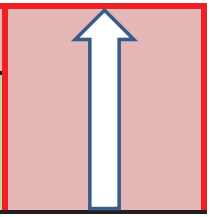
Comparison Factor / Software	Date	Time 1st Time	Time 2nd Time	Clicks	Steps	Difficulties	Variables	Notes	Comparison Factor / Geometries	Results
Revit Architecture	18.02.2011	00:00:28 ✔		17	9		- Tired (Bad Mood) - Optimistic.			
Rhino	18.02.2011	00:03:13 ✔		120	18	*Rhinoceros has no components. It is not a BIM application. Therefore, the resulted geometry is exported to a BIM software to make a real building.	- Tired (Bad Mood) - Optimistic.			

Appendix F

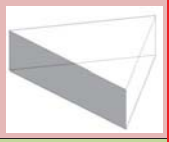
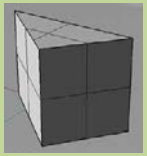
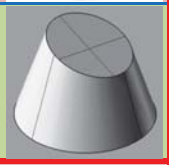
The collected data and the results of the Confirmation Method

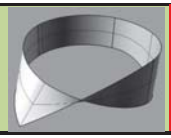
Computer 3 **Experiments:**

Comparison Factor / *Software*	*Date*	*Time* 1st Time	*Time* 2nd Time	*Clicks*	*Steps*	*Difficulties*	*Variables*	*Notes*	*Comparison Factor* / *Geometries*	*Result*
Revit Architecture	25.02.2011	00:01:43 ✔			12		• Good Experience • Bad Mood • Conceptual Design(Not Geometry) • Optimistic • Poor Attitude Two to three Negative variables	PF -First time. -Successful experiment.	*Prism* 	
Rhino	25.02.2011	00:01:01 ✔			7		• Good Experience • Bad Mood • Conceptual Design (Geometric). • Optimistic • Good Attitude One Negative variable	-First time. -Successful experiment.		
Revit Architecture	25.02.2011	00:12:22 ✔			32	* Move items in Elevation view. *Rotate items in elevation View.	Two to three Negative variables	PF -First time. -Successful experiment.	*Right Circular Cone* 	
Rhino	25.02.2011	00:01:04 ✔			16		One Negative variable	-First time. -Successful experiment.		

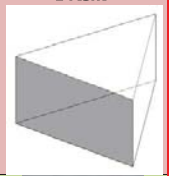
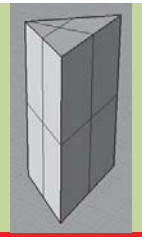
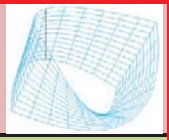
Revit Architecture	25.02.2011	00:26:07✕					Two to three Negative variables	PF -One time. -Failed experiment.	*Mobuis Strip*	
Rhino	25.02.2011	00:14:33✕					One Negative variable	-One time. -Failed experiment.		

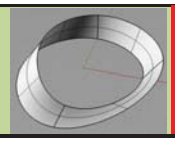
Computer 5 Experiments Analysis:

Comparison Factor *Software*	*Date*	*Time* *1st Time*	*2nd Time*	*Clicks*	*Steps*	*Difficulties*	*Variables*	*Notes*	*Comparison Factor* *Geometries*	*Result*
Revit Architecture	25.02.2011	00:00:57 ✔			**11**		• Good Experience • Bad Mood • Conceptual Design(No Geometry). • Optimistic • Poor Attitude **Two to three Negative variables**	**PF** -First time. -Successful experiment.	***Prism*** 	
Rhino	25.02.2011	00:00:34 ✔			**11**		• Good Experience • Bad Mood • Conceptual Design (Geometry). • Optimistic • Good Attitude **One Negative variable**	-First time. -Successful experiment.		
Revit Architecture	25.02.2011	00:03:02 ✔			**34**		**Two to three Negative variables**	**PF** -First time. -Semi-Successful experiment.	***Right Circular Cone*** 	
Rhino	25.02.2011	00:00:45 ✔			**15**		**One Negative variable**	-First time. -Successful experiment.		
Revit Architecture	25.02.2011	00:09:07 ✘						**PF** -Failed try.	***Mobuis Strip***	
		00:09:00 ✘						-Failed try.		
		00:05:43 ✘						-Failed try.		
		00:14:36 ✔			**36**		• Good Experience • Bad Mood • Conceptual Design(No Geometry). • Pessimistic. • Poor Attitude **Two to three Negative variables**	-Fourth time. -Semi-Successful experiment.		

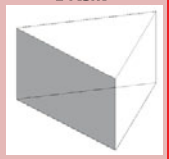
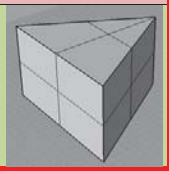
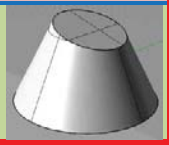
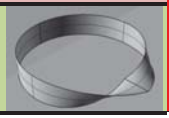
Rhino	25.02.2011	00:03:12 ✔			**29**		**Two to three Negative variables**	**-One time.** **-Semi-Successful experiment.**		

Computer 6 Experiments Analysis:

Comparison Factor / *Software*	*Date*	*Time* 1st Time	*Time* 2nd Time	*Clicks*	*Steps*	*Difficulties*	*Variables*	*Notes*	*Comparison Factor* / *Geometries*	*Result*
Revit Architecture	25.02.2011	00:02:28 ✔			**11**		• Poor Experience • Good Mood • Conceptual Design(Geometry). • Optimistic • Poor Attitude. **Two to three Negative variables**	**PF** **-First time.** **-Successful experiment.**	***Prism*** 	
Rhino	25.02.2011	00:00:20 ✔			**6**		• Good Experience • Good Mood • Conceptual Design(Geometry). • Optimistic • Good Attitude. **All variables are Positive**	**-First time.** **-Successful experiment.**		
Revit Architecture	25.02.2011	00:02:39 ✘			**----**		**Two to three Negative variables**	**PF** **-First time.** **-Failed experiment.**	***Right Circular Cone***	
Rhino	25.02.2011	00:00:58 ✔			**12**		**All variables are Positive**	**-First time.** **-Successful experiment.**		
Revit Architecture	25.02.2011	00:33:27 ✘					**Two to three Negative variables**	**PF** **-Failed try.**	***Mobuis Strip***	
		00:10:23 ✔			**33**			**-Fourth time.** **-Semi-Successful Experiment.**		
Rhino	25.02.2011	00:07:23 ✘				*Problems with Mirror option.	**All variables are Positive**	**-Failed try.**		
		00:06:50 ✔			**13**			**-Second time.** **-Successful experiment.**		

		00:04:26 ✔			**17**			-Third time. -Successful experiment.		

Computer 65 Experiments Analysis:

Comparison Factor / *Software*	*Date*	*Time* 1st Time	*Time* 2nd Time	*Clicks*	*Steps*	*Difficulties*	*Variables*	*Notes*	*Comparison Factor* / *Geometries*	*Result*
Revit Architecture	26.02.2011	00:03:23 ✔			**11**		• Poor Experience • Bad Mood • No Conceptual Design(Geometry). • Optimistic • Poor Attitude. **Four or more Negative variables**	**PF** **-First time.** **-Successful experiment.**	***Prism*** 	
Rhino	26.02.2011	00:02:12 ✔			**9**		• Good Experience • Bad Mood • Conceptual Design(Geometry). • Optimistic • Good Attitude. **One Negative variable**	**-First time.** **-Successful experiment.**		
Revit Architecture	26.02.2011	00:09:10 ✘					**Four or more Negative variables**	**PF** **-First time.** **-Failed experiment.**	***Right Circular Cone***	
Rhino	26.02.2011	00:00:53 ✔			**24**		**One Negative variable**	**-First time.** **-Successful experiment.**		
Revit Architecture	26.02.2011	----------					• Poor Experience • Bad Mood • No Conceptual Design(Geometry). • Pessimistic. • Poor Attitude. **All variables are Negative**	**-No experiment.**	***Mobuis Strip***	
Rhino	26.02.2011	00:13:12 ✘					**One Negative variable**			
		00:04:04 ✔			**18**			**-Second time.** **-Successful experiment.**		
		00:14:31 ✘	00:05:31 ✔							

Appendix G.1
Pre-Questionnaire

Pre- Questionnaire

Hi everyone,

Thank you for your coming today to participate in the experiment.
Please fill out this questionnaire before starting work on the experiment.

1) *Please write down* **the number of your computer*:***

2) How do you feel today? (Calderon et al. 2000, 5)

- ☐ Enthusiastic
- ☐ Comfort
- ☐ Tired
- ☐ Sleepy
- ☐ Discomfort
- ☐ Other (Please Specify):

3) Did you work on ***Autodesk Revit Architecture*** before?

Please select

4) When did you learn using **Revit Architecture**?

dd
mm
*yyyy

5) How did you learn **Revit Architecture**?

- ☐ College course
- ☐ Private training
- ☐ Friend helped me
- ☐ Training books
- ☐ Training videos
- ☐ By myself

Other (Please Specify): _____

6) How often do you use **Revit Architecture**?

- ☐ Always
- ☐ Sometimes
- ☐ Rarely
- ☐ Never

7) Do you use **Revit Architecture** for.....

- ☐ College assignment
- ☐ Job
- ☐ Fun
- ☐ Everything
- ☐ NA
- ☐ Other (Please Specify): _____

8) How many hours do you work on **Revit Architecture** weekly? (Calderon et al. 2000, 5)

- ☐ 0
- ☐ 2
- ☐ 4
- ☐ 6
- ☐ 8
- ☐ 10
- ☐ More...

9) How do you consider your experience in **Revit Architecture*?***

- Beginner
- Moderate
- Expert

10) Do you use **Revit Architecture** in architectural design?

Please select

11) Have you worked on **Revit Architecture** in creating concepts for design project?

Please select

12) If yes, your previous experiments in creating concepts in **Revit Architecture** were....

- Successful
- Successful to some extent
- Had some difficulties
- Failed

13) If you faced some difficulties in using **Revit Architecture**, what are those difficulties? *Please list them....*

14) Have you ever created a pure geometry in **Revit Architecture**?

such as Sphere, Cube, Octagon, pyramid... etc?

Please select

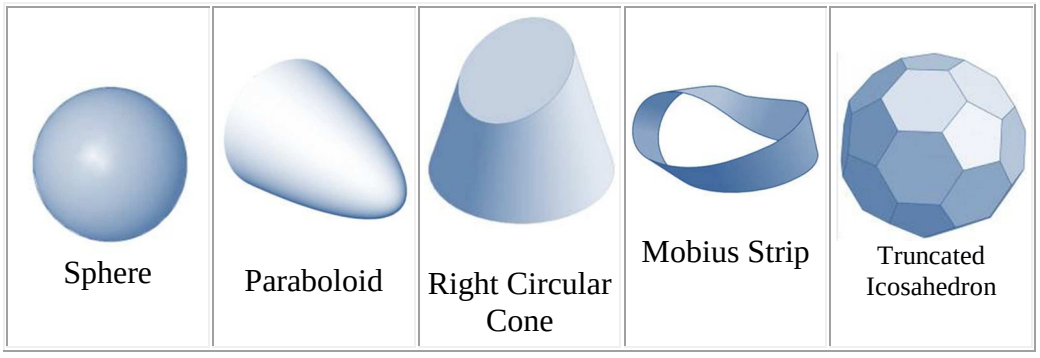
15) If yes, What geometries did you create before in **Revit Architecture**? (*Please list the geometries that you created*)

16) Did you create this/those geometry/ies for design concept?

Please select

17) If you answered **NO**, why did you create it/them?

18) Do you expect **Revit Architecture** is able to create those geometries?



Sphere

Paraboloid

Right Circular Cone

Mobius Strip

Truncated Icosahedron

19) Did you work on **Rhinoceros** before?

Please select

20) When did you learn using **Rhinoceros**?

dd

mm

*yyyy

21) How did you learn **Rhinoceros**?

- ☐ College course
- ☐ Private training
- ☐ Friend helped me
- ☐ Training books
- ☐ Training videos
- ☐ By myself

Other (Please Specify):

22) How often do you use **Rhinoceros**?

- ☐ Always
- ☐ Sometimes
- ☐ Rarely
- ☐ Never

23) Do you use **Rhinoceros** for.....

- ☐ College assignment
- ☐ Job
- ☐ Fun
- ☐ Everything
- ☐ NA
- ☐ Other (Please Specify):

24) How many hours do you work on **Rhinoceros** weekly?

- ☐ 0
- ☐ 2
- ☐ 4
- ☐ 6
- ☐ 8
- ☐ 10
- ☐ More...

25) How do you consider your experience in **Rhinoceros*?***

- ☐ Beginner
- ☐ Moderate
- ☐ Expert

26) Do you use **Rhinoceros** in architectural design?

Please select

27) Have you worked on **Rhinoceros** in creating concepts for design project?

Please select

28) If yes, your previous experiments in creating concepts in **Rhinoceros** were....

- ☐ Successful
- ☐ Successful to some extent
- ☐ Had some difficulties
- ☐ Failed

29) If you faced some difficulties in using **Rhinoceros** what are those difficulties? *Please list them....*

30) €Have you ever created a pure geometry in **Rhinoceros**? Such as Sphere, Cube, Octagon, pyramid... etc?

Please select

31) If yes, What geometries did you create before in **Rhinoceros**? (*Please list the geometries that you created*)

32) Did you create this/those geometry/ies for design concept?

Please select

33) If you answered **NO**, why did you create it/them?

34 Do you expect **Rhinoceros** is able to create those geometries?

)

Sphere	Paraboloid	Right Circular Cone	Mobius Strip	Truncated Icosahedron
				

Easy to create **Moderate** **Difficult** **Never**

Sphere

Paraboloid

Right Circular Cone

Mobius Strip

Truncated Icosahedron

Appendix G.2

The Results of Pre-Questionnaire

Results for: Pre- Questionnaire

1) *Please write down* **the number of your computer:**

Average: 16.00
Range: 1<=>65
Median: 5
Total Responses: 5

2) How do you feel today?

	Percentage	Responses
Enthusiastic	0.0	0
Comfort	0.0	0
Tired	80.0	4
Sleepy	20.0	1
Discomfort	0.0	0
Other	0.0	0
Total responses:		**5**

3) Did you work on ***Autodesk Revit Architecture*** before?

	Percentage	Responses
Yes	100.0%	5
No	0.0%	0
Total responses:		**5**

4) When did you learn using **Revit Architecture**?

1. dd :
2. mm :
3. yyyy:

5) How did you learn **Revit Architecture**?

	Percentage	Responses
College course	0.0	0
Private training	0.0	0
Friend helped me	0.0	0
Training books	16.7	1
Training videos	0.0	0
By myself	66.7	4
Other	16.7	1

6) How often do you use **Revit Architecture**?

	Percentage	Responses
Always	0.0	0
Sometimes	60.0	3
Rarely	20.0	1
Never	20.0	1
Total responses:		**5**

7) Do you use **Revit Architecture** for.....

	Percentage	Responses
College assignment	40.0	2
Job	40.0	2
Fun	0.0	0
Everything	0.0	0
NA	20.0	1
Other	0.0	0
Total responses:		**5**

8) How many hours do you work on **Revit Architecture** weekly?

	Percentage	Responses
0	20.0	1
2	40.0	2
4	20.0	1
6	0.0	0
8	0.0	0
10	20.0	1
More...	0.0	0
Total responses:		**5**

9) how do you consider your experience in **Revit Architecture**?

	Percentage	Responses
Beginner	40.0	2
Moderate	60.0	3
Expert	0.0	0
Total responses:		**5**

10) Do you use **Revit Architecture** in architectural design?

	Percentage	Responses
Yes	60.0%	3
No	40.0%	2

No		40.0%	2
		Total responses:	**5**

11) Have you worked on **Revit Architecture** in creating concepts for design project?

		Percentage	Responses
Yes		80.0%	4
No		20.0%	1
		Total responses:	**5**

12) If yes, your previous experiements in creating concepts in **Revit Architecture** were....

		Percentage	Responses
Successful		20.0	1
Successful to some extent		0.0	0
Had some difficulties		60.0	3
Failed		20.0	1
		Total responses:	**5**

13) If you faced some difficulties in using **Revit Architecture**, what are those difficulties? *Please list them....*

(The last five responses are given)

- **Design limitation in part due to lack of knowledge in the software**
- **Difficulty creating advanced geometries and getting them to work with the standardized building elements**
- **-lining up geometries**
-making parametric families
- **it takes a large body on knowledge to use revit well. I did not fully understand how to use the families functionalities to produce the custom elements of my project**
- **learning the interface and how to complete certain tasks such as custom curtain walls.**

14) Have you ever created a pure geometry in **Revit Architecture**? such as Sphere, Cube, Octagon, pyramid... etc?

		Percentage	Responses
Yes		40.0%	2
No		60.0%	3
		Total responses:	**5**

15) If yes, What geometries did you create before in **Revit Architecture**? (*Please list the geometries that you created*)

(The last five responses are given)

- **cube, pyramid**

- **cube, planes, conceptual masses, etc..**

---

16) Did you create this/those geometry/ies for design concept?

		Percentage	Responses
Yes		50.0%	1
No		50.0%	1
		Total responses:	**2**

---

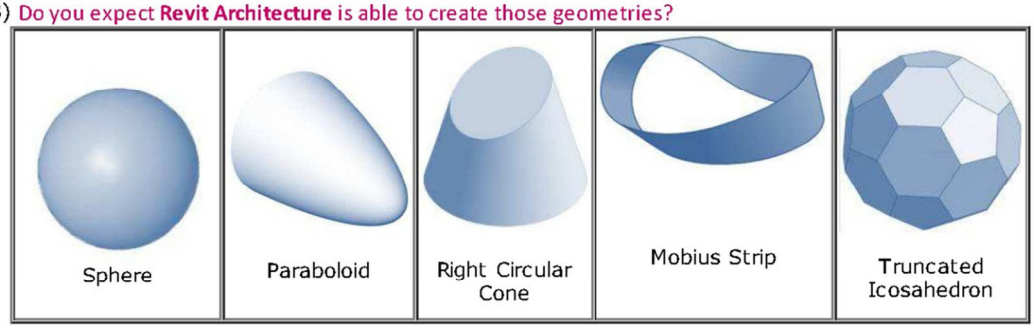
17) If you answered **NO**, why did you create it/them?

(The last five responses are given)

- **to teach a class that it is possible**

---

18) Do you expect **Revit Architecture** is able to create those geometries?



	Easy to create	Moderate	Difficult	Never	Responses	Average Score
Sphere	**4 (80.00%)**	1 (20.00%)	0 (0.00%)	0 (0.00%)	5	1.20 / 4 (30.00%)
Paraboloid	**2 (40.00%)**	1 (20.00%)	**2 (40.00%)**	0 (0.00%)	5	2.00 / 4 (50.00%)
Right Circular Cone	**3 (60.00%)**	1 (20.00%)	1 (20.00%)	0 (0.00%)	5	1.60 / 4 (40.00%)
Mobius Strip	0 (0.00%)	2 (40.00%)	**3 (60.00%)**	0 (0.00%)	5	2.60 / 4 (65.00%)
Truncated Icosahedron	0 (0.00%)	0 (0.00%)	**5 (100.00%)**	0 (0.00%)	5	3.00 / 4 (75.00%)
						2.08 / 4 (52.00%)

---

19) If you answered **NO**, why did you create it/them?

(The last five responses are given)

20) How did you learn **Revit Architecture**?

	Percentage	Responses
College course	0	0
Private training	0	0
Friend helped me	0	0
Training books	0	0
Training videos	0	0
By myself	0	0
Other	0	0

21) Did you work on **Rhinoceros** before?

	Percentage	Responses
Yes	100.0%	5
No	0.0%	0
	Total responses:	**5**

22) How did you learn **Revit Architecture**?

	Percentage	Responses
College course	0	0
Private training	0	0
Friend helped me	0	0
Training books	0	0
Training videos	0	0
By myself	0	0
Other	0	0

23) When did you learn using **Rhinoceros**?

1. dd :
2. mm :
3. yyyy:

24) How did you learn **Rhinoceros**?

	Percentage	Responses
College course	25.0	2
Private training	12.5	1
Friend helped me	0.0	0
Training books	0.0	0

Training books		0.0	0
Training videos		12.5	1
By myself		50.0	4
Other		0.0	0

25) How often do you use **Rhinoceros**?

	Percentage	Responses
Always	80.0	4
Sometimes	20.0	1
Rarely	0.0	0
Never	0.0	0
Total responses:		**5**

26) Do you use **Rhinoceros** for.....

	Percentage	Responses
College assignment	60.0	3
Job	0.0	0
Fun	0.0	0
Everything	40.0	2
NA	0.0	0
Other	0.0	0
Total responses:		**5**

27) How many hours do you work on **Rhinoceros** weekly?

	Percentage	Responses
0	0.0	0
2	0.0	0
4	0.0	0
6	0.0	0
8	0.0	0
10	20.0	1
More...	80.0	4
Total responses:		**5**

28) how do you consider your experience in **Rhinoceros**?

	Percentage	Responses
Beginner	0.0	0
Moderate	0.0	0
Expert	100.0	5
Total responses:		**5**

29) Do you use **Rhinoceros** in architectural design?

29) Do you use Rhinoceros in architectural design?

	Percentage	Responses
Yes	100.0%	5
No	0.0%	0
	Total responses:	**5**

30) Have you worked on **Rhinoceros** in creating concepts for design project?

	Percentage	Responses
Yes	100.0%	5
No	0.0%	0
	Total responses:	**5**

31) If yes, your previous experiements in creating concepts in **Rhinoceros** were....

	Percentage	Responses
Successful	100.0	5
Successful to some extent	0.0	0
Had some difficulties	0.0	0
Failed	0.0	0
	Total responses:	**5**

32) If you faced some difficulties in using **Rhinoceros** what are those difficulties? *Please list them....*

(The last five responses are given)

- **Most difficulties are solved through the use of plugins and scripts**
- **rhino has issues with triangles, limits of my imagination**

33) Have you ever created a pure geometry in **Rhinoceros**? such as Sphere, Cube, Octagon, pyramid... etc?

	Percentage	Responses
Yes	100.0%	5
No	0.0%	0
	Total responses:	**5**

34) If yes, What geometries did you create before in **Rhinoceros**? (*Please list the geometries that you created*)

(The last five responses are given)

- **Cube (box)**
- **sphere, ellipsoid cube box octagon pyramid... more**
- **sphere, cube, triangular prism, cone....**
- **I have created, every type of basic geometry from cubes to hexagonal domes and then**

I have created, every type of basic geometry from cubes to hexagonal domes and then abstracted them from that point to build complexity.

- **cube, rectangular prism, triangular prism, cone, cylinder**

---

35) Did you create this/those geometry/ies for design concept?

	Percentage	Responses
Yes	100.0%	5
No	0.0%	0
	Total responses:	**5**

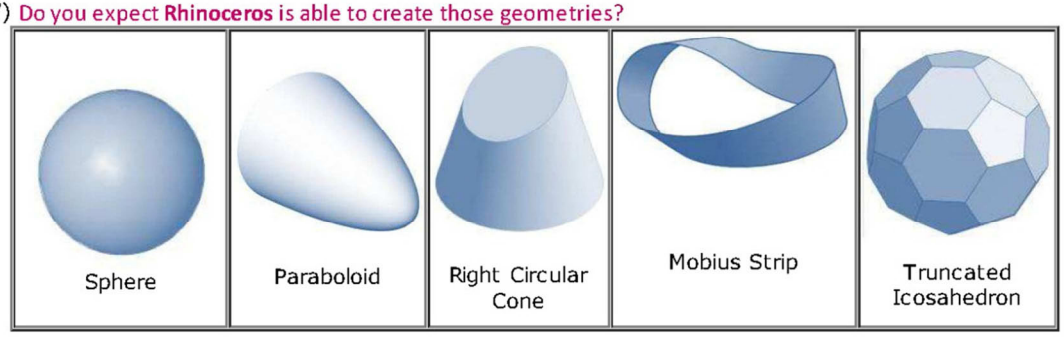
---

36) If you answered **NO**, why did you create it/them?

(The last five responses are given)

---

37) Do you expect **Rhinoceros** is able to create those geometries?



	Easy to create	Moderate	Difficult	Never	Responses	Average Score
Sphere	**5 (100.00%)**	0 (0.00%)	0 (0.00%)	0 (0.00%)	5	1.00 / 4 (25.00%)
Paraboloid	**4 (80.00%)**	1 (20.00%)	0 (0.00%)	0 (0.00%)	5	1.20 / 4 (30.00%)
Right Circular Cone	**4 (80.00%)**	1 (20.00%)	0 (0.00%)	0 (0.00%)	5	1.20 / 4 (30.00%)
Mobius Strip	1 (20.00%)	**4 (80.00%)**	0 (0.00%)	0 (0.00%)	5	1.80 / 4 (45.00%)
Truncated Icosahedron	0 (0.00%)	**3 (60.00%)**	2 (40.00%)	0 (0.00%)	5	2.40 / 4 (60.00%)
						1.52 / 4 (38.00%)

Appendix G.3

Post-Questionnaire

Post-Questionnaire

Thank you for working on the experiment.
Please answer this evaluation of your experience with Revit Architecture...

1) Please write down **the number of your computer**....

2) Please note that **All questions** in this questionnaire are only about your experiment with **Autodesk Revit Architecture**...

	Disagree	Undecided	Agree
I felt comfortable during using Revit Architecture in this task.			
I enjoyed the experiment with Revit Architecture.[63]			
I think this software has made me have a headache on occasion.[63]			
The information (such as online help, on-screen messages, and other documentation) provided with this system is clear. [64]			

[63]Software Usability Measurement Inventory, "Software Usability Measurement Inventory (SUMI)," http://sumi.ucc.ie/index.html. (Accessed January 15, 2011).
[64]James Lewis, "IBM computer usability satisfaction questionnaires: Psychometric evaluation and instructions for use," *International Journal of Human-Computer Interaction* 7, no. 1 (January 1995): 57-78. http://www.informaworld.com/openurl?genre=article&doi=10.1080/10447319509526110&magic=crossref||D404A21C5BB053405B1A640AFFD44AE3, 31.

The organization of the menus or information lists seems quite logical.[65]
The software allows the user to be economical of keystrokes.[63]
Shifting among the views is easy.
The symbols of interface's icons are related to their tasks.
I sometimes wonder if I'm using the right command.[63]
It is easy to forget how to do things with this software.[63]
Tasks can be performed in a straight-forward manner.[63]
I have to look for assistance most times when I use this software.[63]
I find that the online help information given by this software is useful.[63]
I used other online help during my work (web site, videos....etc.).
Error message are helpful. [66]

[65]Chin, John P et al.," Development of an instrument measuring user satisfaction of the human-computer interface," (Paper presented at SIGCHI conference on Human factors in computing systems (CHI '88),New York, NY, USA, 1988), 213-218, http://doi.acm.org/10.1145/57167.57203

I like using the interface of this system. [66]
Overall, I am satisfied with how easy it is to use Revit in creating the geometry.[66]
Revit is easy to model any geometry.
It is fun to use.[67]
I would not like to use this software every day.
I would recommend it to a friend. [67]
I expected that Revit was able to create that geometry.
I would find it easy to get Revit to do what I want it to do. [67]
It requires the fewest steps possible to accomplish what I want to do with it. [67]
The software hasn't always done what I was expecting.
Revit has all the functions and capabilities I expect it to have to create the geometry.

[66]James Lewis, "IBM computer usability satisfaction questionnaires: Psychometric evaluation and instructions for use," *International Journal of Human-Computer Interaction* 7, no. 1 (January 1995) http://www.informaworld.com/openurl?genre=article&doi=10.1080/10447319509526110&magic=crossref||D404A21C5BB053405B1A640AFFD44AE3, 31.

[67] Arnold M. Lund, "Measuring Usability with the USE Questionnaire," *STC Usability SIG Newsletter* 8, no. 2, (October, 2001), http://www.stcsig.org/usability/newsletter/0110_measuring_with_use.html.

I think I can use it successfully every time. [67]
Revit acts with my action.
I sometimes don't know what to do next with this software.
It saves me time when I use Revit in creating geometries.[67]
Using Revit in future would improve my job performance.

3) If you have any additional comments about using Revit Architecture in creating geometries such as (advantages, difficulties that you faced during the task, disadvantages, future recommendations.... etc.), please write them down.

Appendix G.4

The Results of Post-Questionnaire

Results for: Post-Questionnaire

1) Please write down **the number of your computer....**

Average: 16.00

Range: 1<=>65

Median: 5

Total Responses: 5

2) Please note that **All questions** in this questionnaire are only about your experiment with **Autodesk Revit Architecture...**

	Disagree	Undecided	Agree	Responses	Average Score
I felt comfortable during using Revit Architecture in this task.	**4 (80.00%)**	0 (0.00%)	1 (20.00%)	5	1.40 / 3 (46.67%)
I enjoyed the experiment with Revit Architecture.	**2 (40.00%)**	1 (20.00%)	**2 (40.00%)**	5	2.00 / 3 (66.67%)
I think this software has made me have a headache on occasion.	1 (20.00%)	0 (0.00%)	**4 (80.00%)**	5	2.60 / 3 (86.67%)
The information (such as online help, on-screen messages, and other documentation) provided with this system is clear.	**2 (40.00%)**	**2 (40.00%)**	1 (20.00%)	5	1.80 / 3 (60.00%)
The organization of the menus or information lists seems quite logical.	2 (40.00%)	**3 (60.00%)**	0 (0.00%)	5	1.60 / 3 (53.33%)
The software allows the user to be economic of keystrokes.	**2 (40.00%)**	**2 (40.00%)**	1 (20.00%)	5	1.80 / 3 (60.00%)
Shifting among the views is easy.	**3 (60.00%)**	1 (20.00%)	1 (20.00%)	5	1.60 / 3 (53.33%)
The symbols of interface's icons are related to their tasks.	0 (0.00%)	1 (20.00%)	**4 (80.00%)**	5	2.80 / 3 (93.33%)
I sometimes wonder if I'm using the right command.	1 (20.00%)	1 (20.00%)	**3 (60.00%)**	5	2.40 / 3 (80.00%)
It is easy to forget how to do things with this software.	1 (20.00%)	1 (20.00%)	**3 (60.00%)**	5	2.40 / 3 (80.00%)
Tasks can be performed in a straight-forward manner.	**4 (80.00%)**	1 (20.00%)	0 (0.00%)	5	1.20 / 3 (40.00%)
I have to look for assistance most times when I use this software.	**2 (40.00%)**	1 (20.00%)	**2 (40.00%)**	5	2.00 / 3 (66.67%)
I find that the online help information given by this software is useful.	**2 (40.00%)**	**2 (40.00%)**	1 (20.00%)	5	1.80 / 3 (60.00%)
I used other online help during my work (web site, videos....etc).	2 (40.00%)	0 (0.00%)	**3 (60.00%)**	5	2.20 / 3 (73.33%)
Error message are helpful.	**3 (60.00%)**	2 (40.00%)	0 (0.00%)	5	1.40 / 3 (46.67%)
I like using the interface of this system.	**5 (100.00%)**	0 (0.00%)	0 (0.00%)	5	1.00 / 3 (33.33%)
Overall, I am satisfied with how easy it is to use Revit in creating the geometry.	**5 (100.00%)**	0 (0.00%)	0 (0.00%)	5	1.00 / 3 (33.33%)
Revit is easy to model any geometries.	**5 (100.00%)**	0 (0.00%)	0 (0.00%)	5	1.00 / 3 (33.33%)

It is fun to use.	**3 (60.00%)**	2 (40.00%)	0 (0.00%)	5	1.40 / 3 (46.67%)
I would not like to use this software every day.	2 (40.00%)	0 (0.00%)	**3 (60.00%)**	5	2.20 / 3 (73.33%)
I would recommend it to a friend.	**2 (40.00%)**	1 (20.00%)	**2 (40.00%)**	5	2.00 / 3 (66.67%)
I expected that Revit was able to create that geometry.	0 (0.00%)	1 (20.00%)	**4 (80.00%)**	5	2.80 / 3 (93.33%)
I would find it easy to get Revit to do what I want it to do.	**4 (80.00%)**	1 (20.00%)	0 (0.00%)	5	1.20 / 3 (40.00%)
It requires the fewest steps possible to accomplish what I want to do with it.	**4 (80.00%)**	1 (20.00%)	0 (0.00%)	5	1.20 / 3 (40.00%)
The software hasn't always done what I was expecting.	0 (0.00%)	0 (0.00%)	**5 (100.00%)**	5	3.00 / 3 (100.00%)
Revit has all the functions and capabilities I expect it to have to create the geometry.	**2 (40.00%)**	**2 (40.00%)**	1 (20.00%)	5	1.80 / 3 (60.00%)
I think I can use it successfully every time.	**3 (60.00%)**	2 (40.00%)	0 (0.00%)	5	1.40 / 3 (46.67%)
Revit acts with my action.	**2 (40.00%)**	**2 (40.00%)**	1 (20.00%)	5	1.80 / 3 (60.00%)
I sometimes don't know what to do next with this software.	1 (20.00%)	1 (20.00%)	**3 (60.00%)**	5	2.40 / 3 (80.00%)
It saves me time when I use Revit in creating geometries.	**5 (100.00%)**	0 (0.00%)	0 (0.00%)	5	1.00 / 3 (33.33%)
Using Revit in future would improve my job performance.	**4 (80.00%)**	0 (0.00%)	1 (20.00%)	5	1.40 / 3 (46.67%)
					1.79 / 3 (59.78%)

3) If you have any additional comments about using Revit Architecture in creating geometries such as (advantages, difficulties that you faced during the task, disadvantages, future recommendations.... etc), please write them down.

(The last five responses are given)

- I did not complete the task as I became frustrated with the software. As I have never dealt with a Mobius before, I already became frustrated by the introduction of unkown geometry within a constricted time setting. I then further frustrated by the limitations of revit that I simply quit.

- Revit is more time consuming to search for proper commands or to know of commands. I also feel that there are too few of options given by Revit, where as Rhino has multiple means of achieving a task.

- some differences between mac and pc were hard to adjust to, ie different shortcuts.... revit is good at making solids and does a poor job of making complex surfaces

- the massing interface needs to make it easier to select planes to work in and manipulate geometry. It has come along ways but the ease of other 3d software makes importing a base geometry smoother than creating the geometry directly in revit. I don't like the rigidity of the program

- only advantage for geometry is being able to drag the corner points and edges easily to deform shapes.

Appendix H.1

Informed Consent

University of Nebraska Lincoln

COLLEGE OF ARCHITECTURE
Architecture & Interior Design Programs

Informed consent to Participate in Research

TITLE of study: **BIM Applications in Conceptual Design Phase: Exploring the Abilities and Limitations of Revit by applying Generative Geometric Design Approach.**

Person in Charge of Study: **Sara A. Ben Lashihar**

We invite you to take part in a research study being conducted at the University of Nebraska- Lincoln. It is important that you read and understand several general principles that apply to all who take part in this research study: (1) taking part in this study is entirely voluntary; (b) you may not benefit directly as a result of taking part in this study, but knowledge may be gained that might benefit others; (c) you are free to withdraw from the study at any time without affecting your relationship with the investigators or the university of Nebraska-Lincoln; (d) leaving the study will not cause a penalty or loss of any benefits to which you are otherwise entitled.
Before you volunteer to take part in this research, the study must be explained to you and you must be given a change to ask questions. You should discuss anything that you do not understand with the person who is explaining it to you before you agree to volunteer. Once all of you questions have been answered, you must sign this consent form, which gives us permission for you to participate. You will be given a copy of the signed consent form to take home with you. The nature of the study, the risks, inconvenience, discomforts and other important information about the study are discussed below.

1. What is the purpose of this study?
The study examines the abilities, and explores limitations and possibilities of Autodesk Revit Architecture in a particular design approach called Generative Geometric Design Approach (GGDA). It investigates Revit's reliability, and presents a clear picture about its compatibility with GGDA.

2. Why are being invited to take part in this research
You are being invited to take part in this research because of your good knowledge and background about Revit and Rhinoceros softwares. That knowledge will contribute significantly to examine those two softwares, and will help to explore their abilities and limitations.

3. Are there reasons why you are not eligible to participate in this study?
The volunteers for this study should be 19 years of age or over, UNL-College of Architecture students, and have previous experience in using Autodesk Revit Architecture software and Rhinoceros software.

Room 232 Architecture Hall / P.O. Box 880107 / Lincoln, NE 68588-0107
(402) 472-9233 / FAX (402) 472-3806 / Email: architecture2@unl.edu / http://archweb.unl.edu

4. Where is the study going to take place?
The study will take place in basement computer lab in Architecture Hall building.

5. How long will the participation in this study last?
At the beginning, the students are required to fill out a questionnaire via the internet. Then, they will be given instructions of the two experiments that they will work on. In the first experiment, the participants will work on Rhinoceros software to create a specified geometry. In the second experiment, they will work on Revit to create a different geometry. After completing the two experiments, the participants will be asked to answer another questionnaire through the internet. The entire process will take place in the basement computer lab in Architecture Hall building, and will last two to three hours. During the experiments, the participants will be videotaped by a digital camera to record their behaviors. Also, their computer screens will be recorded by screen capture software to document the steps that they followed in working on each software.

6. What are the possible risks or discomforts?
There are no known risks involved in participating in the project.

7. What are the potential benefits of study participation?
There are no personal benefits from taking part in this study.

8. Will you receive any rewards or compensation for study participation?
There are no rewards or compensation for study participation.

9. What will happen if you decide not to continue in this study?
Participation in this study is voluntary. You can refuse to participate or withdraw at any time without harming your relationship with the researcher or the university of Nebraska-Lincoln, College of Architecture, or in any other way receive a penalty or loss of benefits to which you are otherwise entitled.

10. Who will have access to the information that you provide as a part of this study? How will study information be kept confidential?
The collected data will be kept by the researcher until the end of the research. The researcher only has the access to this information. The results of the study will be published in the research; however, the researcher will keep your personal information private.

11. Who should you contact regarding this study?
You may ask any questions concerning this research and have those questions answered before agreeing to participate in or during the study. You may call the investigator at any time, Sara Ben Lashihar at ( ) - , or email her at _____@huskers.unl.edu. You can also contact Prof. Timothy Hemsath at ( ) - , or email him at _____@unlnotes.unl.ed.

If you have any questions about your rights as a research participant, or to report any concerns about the study, please contact the University of Nebraska-Lincoln Institutional Review Board at (402) 472-6965.

You are voluntary making a decision whether or not to participate in this research study. Your decision to participate or not will not negatively affect your grades. Your signature certifies that you have decided to participate, having read and understood the information presented. It also confirms your agreement to be videotaped during the study and your work will be recorded. You will be given a copy of this consent form to keep.

_____ _____

Signature of person agreeing to take part in the study Date

_____

Printed name of person agreeing to take part in the study.

Appendix H.2

The Announcement Script for the Experiment

Hi everyone, it is nice to meet you today.

My name is Sara; I'm a graduate student in college of architecture.
I came here today to announce my need for volunteers to work on an experiment that is part of my master thesis.

Let me first ask you: "who of you has an experience in working on Rhinoceros and Revit Architecture softwares? Please raise your hand". *(I ask this question to know how many students have the experience to work on my experiment).*

The experiment that I ask you to participate in is an essential part of my master thesis as I mentioned before. In my master thesis, I study how BIM applications can work on conceptual design phase which is an important phase in the entire design process. Knowing the abilities of those applications in that phase will give designers and architects a clear picture about the appropriate software that is suitable for their generative design approaches.

This experiment will last about 2 hours and a half. Half an hour for answering two questionnaires, and other two hours for working on two tasks. In the first task, the participants will work on Rhino, and in the second task they will work on Revit Architecture.

The volunteers of this experiment should be 19 years of age or over, and they should have an experience in using Rhinoceros and Revit Architecture. The volunteers can be beginners to experts in using those softwares. It doesn't matter the level of your experience. The most important thing is that you can use both softwares. During the experiment, you will be videotaped and your work will be recorded to study your generative design approaches in using the softwares.
The experiment is voluntary, and the participants have the right to refuse or withdraw their participations any time which will not affect your grades or your relationship with the professors.

Your participation is important to achieve the goals of that thesis, and it will be a good opportunity to you to try something that you might not try before.
So, if you have any questions about the experiment, don't hesitate to ask me.... *(Try to answer any questions they may ask.).*

(If there are no more questions) Finally, if you want to participate just sign this sheet with your contact information, and I will contact you soon to arrange the day and time of the experiment.

Thank you so much for your listening and I would like to thank the professor (...) for his/her collaboration and for giving me this opportunity to talk to you all.

Appendix H.3

The Email to the Participants

Dear All,

I was pleasure to speak to you the other day, and thank you for your willingness to participate in the experiment of my master thesis. I am looking forward to meeting with you on [Date, ex. February 5] at [Time, ex. 11:00 a.m.] in room [Room Number, ex.212] in Architecture Hall building to work on the project's experiment.

As I mentioned before in my announcement, the experiment includes two tasks. You will work on Rhino and Revit Architecture softwares in those two tasks. In addition, you will answer two questionnaires (Pre-questionnaire and Post-Questionnaire). The experiment is open-book and you may use any written materials, books, websites, online help, software's help, and videos. You may not use any of your previous Revit or Rhino files or any stored files on computer, flash drive or any electronic device.
As a reminder again, you will be videotaped during the experiment, and your computer screen will be recorded. The entire process will last about three hours.

Your attendance and participation are vital to the success of that thesis. However, if you are unable to attend or you want to withdraw your participation, just email me back. Your participation is voluntary and you have the right to refuse or withdraw at any time which will not negatively affect your grades.
I look forward to meeting you. I am certain that you participation will prove productive results to thesis's goals.

Sincerely,

Sara Ben Lashihar
Graduate Student
College of Architecture
University of Nebraska-Lincoln

Appendix H.4

IRB Project Approval Email

From: ……..@unl.edu (……@unl.edu)
To: …….@yahoo.com; …….@unl.edu;
Date: Tue, February 15, 2011 9:45:13 AM
Cc:
Subject: NUgrant Message - IRB Project Approved

Your project has been approved by the IRB.
Project Title: BIM Applications in Conceptual Design Phase: Exploring the Abilities and Limitations of Revit by applying Generative Geometric Design Approach

Approvers Comments:

Ms. Ben Lashihar and Dr. Hemsath,
Your project has been approved. You are authorized to begin data collection.

1. The approved informed consent form has been uploaded to NUgrant (file with -Approved.pdf in the file name). Please use this form to distribute to participants. If you need to make changes to the informed consent form, please submit the revised form to the IRB for review and approval prior to using it.

Your official approval letter will be emailed to you and uploaded to NUgrant shortly. Good luck with your research!

Becky Freeman
000-0000
…….@unl.edu

==========

This message has been sent to you through NUgrant. To view project/form you can click the link below.
If you have any NUgrant questions you can contact nugrant@unl.edu for help.

Appendix H.5

The Instructions of the Experiment in the Confirmation Method

Experiment duration: 2 hours

Instructions to Participants

Please read carefully these instructions and the tasks' requirements:

- Please don't communicate with other participants during the experiment.
- If you wish to leave the room temporarily or leave the examination early you must indicate this to the supervisor.
- If you have any question about the experiment or any technical problem in the computer, please ask the supervisor.
- The experiment is open-book and you may use any written materials, books, websites, online help, software's help, and videos. You may not use any of your previous Revit or Rhino files or any stored files on computer, flash drive or any electronic device.
- Please don't turn off Camtasia or Mouse torn softwares during the experiment.
- You can use this paper for your manual sketches or calculations.
- Please try to work on real building scale.

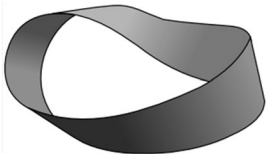
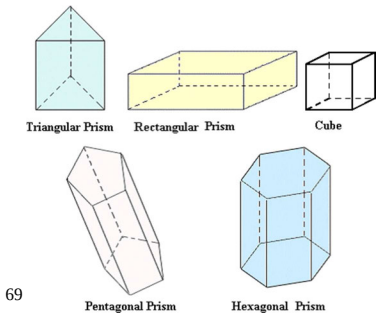
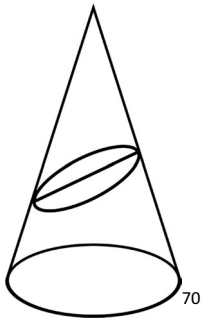
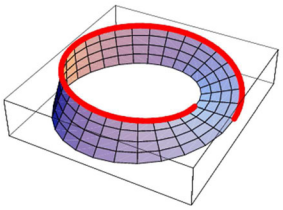
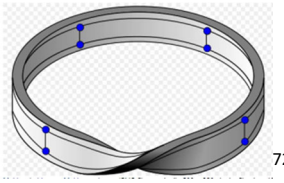
This experiment is two pages long. It consists of two main tasks; the first task will be done by Rhinoceros, and the second task will be done by Revit Architecture 2011. Your job is to create the listed geometry in each task by using the indicated softwares. If you need any information about the instructions and the tasks please ask the instructor.
You will not be penalized if you did not complete the task or did not create the required geometry. It is not an examination, it is study's experiment.

At the end of the experiment, please save your file at folder: Computer>Thawspace.

Rhinoceros Task:

- The used software: Rhinoceros 5.0
- The maximum time of this task duration: 60 min

Please try to create the geometries that are pictured below using Rhinoceros. The provided information will help you to understand the mathematical rules of that geometry.

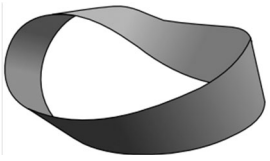
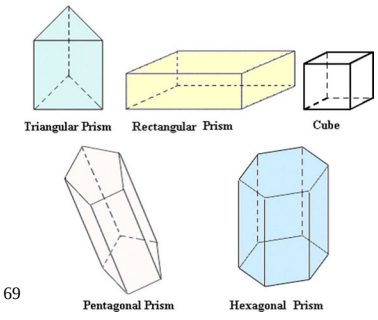
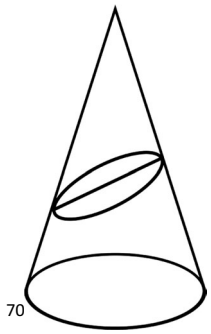
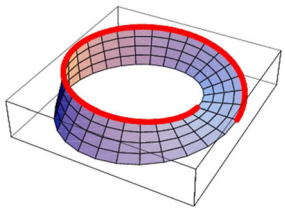
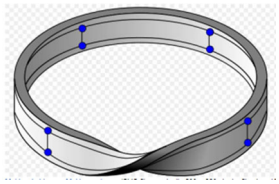
		 68
Triangular Prism	**Right Circular Cone**	**Mobius Strip**
Prism is consisted of two identical shape parallel sides (triangular, circle, or irregular shape). "A prism is called triangular, rectangular, etc., depending on whether the bases are triangular, rectangular, etc."(SpringerLink 2001)  69	Right circular cone is a part of Cone geometry. Any oblique plane can cut the cone into other geometries; the upper part is called Oblique Circular Cone, and the lower part is called right Circular Cone.  70	The Mobius strip, also called the twisted cylinder, is a one-sided nonorientable surface obtained by cutting a closed band into a single strip, giving one of the two ends thus produced a half twist, and then reattaching the two ends.  71  72

[68] "Hair Band clip art," Clker, http://www.clker.com/clipart-24184.html (accessed December 11,2010).
[69] "Prism," iCoachMath, 2011, http://www.icoachmath.com/SiteMap/Prism.html
[70] Florida Center for Instructional Technology, "Conic Section Showing An Ellipse," Clipart ETC, http://etc.usf.edu/clipart/47200/47257/47257_conics_1.htm
[71] Eric Weisstein, "Mobius Strip," Wolfram MathWorld, 2011, http://mathworld.wolfram.com/MoebiusStrip.html

Autodesk Revit Architecture task:

- The used software: Autodesk Revit Architecture 2011.
- The maximum time of this task duration: 60 min.

Please try to create the geometry that pictured below using Rhinoceros. The provided information will help you to understand the mathematical rules of that geometry.

		 68
Triangular Prism	**Right Circular Cone**	**Mobius Strip**
Prism is consisted of two identical shape parallel sides (triangular, circle, or irregular shape). "A prism is called triangular, rectangular, etc., depending on whether the bases are triangular, rectangular, etc."(SpringerLink 2001)  69	Right circular cone is a part of Cone geometry. Any oblique plane can cut the cone into other geometries; the upper part is called Oblique Circular Cone, and the lower part is called right Circular Cone.  70	The Mobius strip, also called the twisted cylinder, is a one-sided nonorientable surface obtained by cutting a closed band into a single strip, giving one of the two ends thus produced a half twist, and then reattaching the two ends.  71  72

[72] "Mobius ladder on Mobius strip," Wikipedia, http://en.wikipedia.org/wiki/File:M%C3%B6bius_ladder_on_M%C3%B6bius_strip.svg